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SOME SUGGESTIONS AS TO SAFETY RULES TO BE PRINTED OR MIMEOGRAPHED FOR THE GUIDANCE OF BITUMINOUS-COAL MINE EMPLOYEES

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By D. Harrington,[2] J. J. Forbes,[3] and W. J. Fene[4]

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6820."
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INTRODUCTION

Although special mining conditions require special rules and no given set of rules will cover every condition in a mine adequately, every mine should have its own specific rules, and there are some general rules that may be applied to virtually any mine. This paper proposes to furnish mining officials with suggestions for the formulation of a set of rules and regulations which may by some modifications be made applicable to the particular conditions in their mine or mines. The rules and regulations of scores of companies have been reviewed, and a compilation has been made of numerous general rules, which any company may use to advantage in formulating regulations for its special requirements though the exact wording in this compilation probably will have to be altered to apply to particular conditions.

NECESSITY FOR SAFETY RULES

Safety rules and regulations are as necessary in industry as civil laws in community life and like civil laws are formulated as the result of violation of basic safety principles or in anticipation of such violation. Practically every progressive mine or plant has safety rules, either verbal or written, upon which safe, efficient operation depends. Safety rules are essential in mining more than in nearly any other industry because of its inherent dangers and because constant supervision is not possible. This is borne out by the fact that in virtually all States where mining is conducted, legislation has been enacted setting forth safety rules by which mines may be operated, though some States have no specific laws or regulations as to safety in the general run of industries. State laws or rules do not begin to cover all conditions in every mine, consequently formulation of additional company or mine rules is necessary to protect the workers and the mining property as well.

Rules are also necessary to provide standard methods of performance for the various jobs. There is at least one right way and there are almost invariably numerous wrong ways to do every job; well-formulated rules or suggestions point out and emphasize the proper method to be employed. Safety rules in printed or multigraphed form prevent disorder and misunderstanding, forestall excuses for not performing a job properly, and indicate not only to workers but also to supervisory officials the minimum safety requirements of the mine-operating company.

The prevention of accidents, like the conduct of any successful venture, can be accomplished only through definite policies of conduct, and there must be rules to govern them.

DEVELOPMENT OF SAFETY RULES

After it has been decided to adopt safety rules for a particular mine a plan for developing must be outlined. In some instances the rules are formulated and approved by one man, usually a managing official, and are liable to be incomplete, because they represent the experience and knowledge of only one man. Obviously, it is better for such rules to represent the combined judgment of several men.

To insure the success of company safety rules the cooperation of mine officials and employees must be enlisted; if the employees are given an opportunity to offer suggestions and to participate in the development of the rules it is probable that their interest and support will be stimulated.

Before a set of rules is finally adopted it is usually advisable to obtain the approval of the officials whose duty it will be to enforce the rules and of the employees or their organizations. It is not likely that complete agreement can be secured, but differences can be discussed and in many instances agreement can be reached by explanation of the necessity for any rule in dispute. If rules are approved before their adoption there is greater likelihood that they will be acceptable to officials and employees and therefore more easily enforced and more willingly carried out. All safety rules should be worded so clearly that there can be no misunderstanding of their meaning. Suggestions might also be included in the rule book, but care should be taken to differentiate between rules and suggestions, as it is not always possible to enforce suggestions. No rules should be included that cannot be readily enforced.

Some companies include in the appendix of their rule books brief instructions in first aid to the injured, with special reference to artificial resuscitation, bleeding, burns, shock, and prevention of infection.

PUBLISHING THE RULES

After a set of rules has been agreed upon and approved, the form of publication must be considered. Some companies print the rules on large placards to be posted on bulletin boards, but a better method is to publish them in booklet form. The advantage of the booklet is that the employee can take it home where he will have time to study it. The booklet should be of convenient size to carry in the pocket and of such construction that it can be amended from time to time as necessity demands.

The contents of the booklet should be arranged with rules applying to all workers grouped at the beginning of the book, followed by those applying to the various jobs, as haulage or mining, a method of doing this being shown later.

THE OFFICIAL, THE EMPLOYEE, AND THE RULES

When the rule books are placed in the hands of the employees the importance of becoming familiar with all the rules should be emphasized. Although an employee may not feel that he should become familiar with other than the general rules and those that apply to his particular job it is desirable that every employee be familiar ultimately with all rules in the booklet.

To convince old employees of the importance of rules is likely to be difficult, especially if there are changes that will impose additional duties upon them, such as placing safety posts or blocking cars; little or no trouble should be experienced with new employees, as they will usually

wish to know the company's desires regarding safety and probably will accept the rules without question. New employees, whether experienced or not, are much more likely to be injured than are those accustomed to the mine, therefore they should be given careful instructions as well as extra supervision for some months.

Many companies provide a detachable page which the employee signs, showing that he has read, or had read to him, the rules and that he understands and will abide by them. Usually this is a matter of form; frequently it is a farce; but if carried into effect, as it should be, it will have definite safety value. Sometimes an oral or written examination is given after the employee has had an opportunity to study the rules; this practice is good and can readily be carried into effect by the bosses on their visits to the working places.

Probably the best method of acquainting employees with the rules is through open meetings of employees and officials or at regular safety meetings or Holmes safety chapter meetings; a good practice is to hold meetings for special groups, such as haulage employees or miners, to discuss the rules covering their particular jobs.

Unless rules are to be rigidly enforced, they had better not be adopted. As enforcement of rules will depend upon the attitude of the foreman, he must first be impressed with their importance and the necessity of observing and enforcing them. Laxity in enforcing rules results in contempt for them by employees, and if a foreman knowingly permits violation of a rule without some reprimand he will find it difficult to demand respect for that rule again; and a foreman who himself violates a company's rule or a State law or regulation is a menace to the community.

The penalties inflicted for violation of safety rules vary according to numerous conditions, including the judgment of the official who sets the penalty and the seriousness and frequency of the offense; many mines have a definite schedule of penalties, ranging from a reprimand to discharge, and it would be good policy for all mines to have a fairly well-standardized system of penalties for infraction of safety rules or regulations.

Under some district agreements between operators and employees the following penalties for violation of rules are provided:

1. For the first offense - warning.

2. For the second offense - reprimand or 2 days' suspension.

3. For the third offense - 5 days' suspension or discharge, at the option of the operator.

In malicious or aggravated cases the mine management has the right to discharge for the first or any subsequent offense.

KEEP SAFE!

RECORD OF UNSAFE PRACTICES

PREVIOUS RECORD OF VIOLATIONS	NAME
	Check No. Working Place

IN THE SPACE PROVIDED BELOW, THE VARIOUS FOREMEN IN CHARGE OF, OR INSPECTING THE WORK IN THIS SECTION WILL NOTE VIOLATIONS OF THE MINING LAWS, OR OF THE RULES OF THE VESTA COAL COMPANY. SUCH VIOLATIONS AS WORKING UNDER DANGEROUS ROOF, INSUFFICIENT POSTING, LOADING CARS ON GRADES WITHOUT SAFETY BLOCKS, ETC., ARE TO BE NOTED. ALSO THE LOADING OF DIRTY COAL, AND CONDITION OF PLACES AS TO BOTTOMS, ETC.

DATE	DESCRIPTION OF VIOLATION	SIGNATURE OF OFFICIAL

RECORD OF ACCIDENTS:

IN THE SPACES BELOW THE FOREMEN WILL DATE THIS CARD ON THEIR VISITS.

FOREMAN

THIS IS A PROTECTION TO

YOURSELF AND FAMILY

DO NOT DEFACE OR DESTROY THIS CARD

Figure 1.—Card to be displayed in working place, giving safety record of each man.

DAILY REPORT ON POTENTIAL HAZARDS

CHECK No.	No. ROOM OR ENTRY	VENTILATION	GAS	BRATTICE STOPPINGS OR	LOOSE ROOF	NEEDS TIMBERING	EXPLOSIVES	ELEC. WIRING	HAULAGE ROADS	TRANSPORTATION	FIRE HAZARD	CARS. BLOCKING. ETC.	CLEARANCE	NEEDS ROCK DUST	OTHER HAZARDS	REMARKS

SPLIT No.	AREA AND VELOCITY	CU. FEET AIR	No. MEN		LOCATION
			DAY	NIGHT	

INLET________ OUTLET________ No. MEN INSIDE________

REV. OF FAN________ WATER GAUGE________

DATE MINE SECTION

MINE OFFICIAL

FORMCMC-79

Figure 2.—Loose-leaf card to be filled in and filed by foreman.

Several methods are used for keeping records of violations of rules, unsafe practices, and unsafe conditions. One method employs a card about 10 by 12 inches, which is nailed to a post in each working place; the cards are provided with spaces where violations may be recorded and are replaced each month, and the old cards filed, giving a complete safety record of each man. Figure 1 illustrates this card. In another method the foreman carries a loose-leaf book containing a small card for each working place, and as he makes his round of inspection he records any safety violations or unsafe practices or conditions observed; these cards are also filed as a permanent record for each man. Figure 2 illustrates this card.

SUGGESTED RULES

The following rules, selected from rule books of numerous companies, should afford a general basis for the formulation of a set of rules, although it is not expected that all will be suitable for every mine; suggestions are given chiefly as examples of what each mine in the United States can and should do in placing before its employees the definite minimum safety requirements of the management.

The cover page of a safety-rules booklet may be worded as follows:

RULES AND REGULATIONS

GOVERNING

OFFICIALS AND EMPLOYEES

OF THE

- - - COAL COMPANY

ISSUED AUGUST 1934

Form of Receipt

The second page may be made detachable, for use as a receipt to be filled in at the time of employment or at a stated period after employment.

Example 1

I hereby acknowledge receipt of copy of book of Rules and Regulations Governing Officials and Employees of the - - - - Coal Co.

I will familiarize myself with the Rules and Regulations contained therein, and with the State mining laws in so far as they relate to my duties in or about the mines, and will comply with them to the best of my ability.

I shall endeavor to make the mine a safer place in which to work, assist the safety committees in the performance of their duties, discourage unsafe practices, and help to make the community a better place in which to live.

____ Mine

Date ____

Signed ____

Occupation ____

Example 2

I have received a copy of the Rules and Regulations of the - - - - Coal Co., have read them (or had them read to me), and fully understand them.

Signed ____

Witness ____

Mine ____

Date ____

Example 3

I hereby acknowledge receipt of a copy of the Rules and Regulations of the - - - - Coal Co.

As a condition of employment, I agree to study and learn the rules, to abide by them, and to be careful to protect myself and fellow workmen from injury.

Name ____

Check No. ____

Occupation ____

Witness ____

Date ____

Preface

Most rule books contain a preface, examples of which are as follows:

Example 1

These rules are made primarily to promote the safety of officials and employees of the - - - - Coal Co. The company expects every employee not only

to observe and obey the rules himself but to do all in his power to prevent their violation by others, as the carelessness of one employee is very likely to result in injury not only to himself but to others as well.

Violation of any rules will subject the offender to discipline and possible discharge. The method of discipline will be left to the management of the mine; it is not expected that severe measures will be taken for minor infractions of the rules, but <u>every violation</u>, no matter how slight, will be noted and steps taken to prevent repetition.

Every employee in and around the mine is requested to report any dangerous condition to the superintendent or mine foreman, or their assistants.

<u>Example 2</u>

The purpose of these rules is to bring out the facts that: (1) The man who is to avoid accidents and reduce loss of life and human suffering must exert every personal effort; (2) all employees, especially those who are inexperienced, should be informed of the dangers incident to mining, so far as it is possible to do so in a set of rules; and (3) precautions must be taken by all employees, experienced or inexperienced, to reduce the hazards of their work to a minimum.

The instructions contained herein deal only with the dangers common to mining in this field and do not cover all those incident to mining, with its many peculiar and ever-changing phases.

The advice and instruction of your foreman and his assistants should be sought when conditions not treated herein present themselves or when more detailed instruction is required for your safety or that of other employees.

Where question or conflict arises between these rules and the mining laws of the State, the mining laws shall govern.

<u>Example 3</u>

The mining laws of the State were enacted to insure the health and safety of persons employed in and about the mines and the protection and preservation of property connected therewith. Employees are required to familiarize themselves with the provisions of these laws. In addition to the provisions of the mining laws the following rules and regulations have been adopted by this company, primarily for the safety and protection of its employees, and the prevention of accidents and as a guide and requirement for the installation and care of equipment.

These rules and regulations have been made for your protection and benefit. You will receive more money through your regular employment than through the accident-compensation payroll; to your family and dependents you are worth more alive and uninjured than you are crippled or dead. No amount of money can compensate for a life, a permanent disability, or some kinds of temporary disability.

Your violation of any of the following rules and regulations, or any of the provisions of the State mining laws, will subject you to disciplinary measures.

GENERAL RULES

The following general rules apply to all employees and are not covered in the rules for individual jobs:

1. Strict compliance with mining laws and safety standards shall be the first duty of each employee at all times.

2. All officials and employees shall cooperate with the State mine inspector in enforcing the law.

3. If in doubt as to the meaning of any rules, an employee shall apply to the foreman or superintendent for explanation.

4. An employee shall know all the special rules covering his work, all the general rules, and the State mining laws and should always report to the foreman anything he thinks may cause accidents.

5. Each employee before entering the mine shall deposit his check on a board provided for that purpose. On leaving the mine each man must remove his check from the check board. Failure to check in and out will be cause for discipline.

6. All employees and visitors must be provided with identification checks before entering the mine.

7. No matches, open lights, cigarettes, or other smoking materials are allowed in the mine; any employee who violates this rule will be subject to prosecution and discharge.

8. The use of goggles, safety shoes, and safety hats is compulsory and every employee must be provided with this protective equipment.

9. Any person wishing to be absent from duty should apply to and receive permission from his immediate superior.

10. To protect the lives of all workmen, it shall be the duty of each employee to report to his foreman any violation of the mining laws or of these rules.

11. Each workman in and around the mine shall personally perform his own duties, and at no time shall he depend upon or ask another workman to do work for him unless such aid is required to prevent personal injury. No workmen, other than those authorized by the foreman, shall in any way tamper with or run any machinery, throw any switches, or in any way tamper with any trip of cars or signal or telephone wire, or do anything else that may endanger the lives of fellow employees.

12. Any person removing any guard or safety device from any mechanical equipment for any reason shall see that such guard or safety device is replaced before the machine is put in operation. If for any cause the guard or safety device cannot be replaced immediately, a warning sign shall be put on the machine, and such machine shall not be operated until the guards or safety devices are in place.

13. Refuse and material shall not be stored or thrown on the clearance side of any entry, in any shelter hole, or in any manway inside the mine.

14. Machinery shall not be repaired or oiled while in motion.

15. Hand tools shall be kept in good condition and mushroomed heads or other dangerous conditions of drills, hammers, cutters, and other tools shall not be permitted. The use of dull picks shall not be permitted.

16. When timberman, rockmen, and others are working in an entry where trolley wire is in place the current shall be cut off, except when there is interference in other operations in the mine. Where the current must be maintained, approved guards shall be placed over the wire at the point where the work is being done.

17. Loaded cars shall not be moved by hand while haulageways where trolley wire is in place are being cleaned.

18. In shaft mines no one shall cross, for any cause whatever, from one side of the shaft to the other through either hoist compartment of the shaft.

19. Any person found with tools or explosives belonging to another, or taking or using tools or explosives belonging to another, without the owner's permission, shall be subject to prosecution and discharge; any person detected changing checks on the pit cars shall be discharged immediately and may also be prosecuted.

20. Whenever it shall be the duty of any person to go into the "sump" or space below the cage at the bottom of the shaft to clean it out or for any other reason he shall first place a proper "dog" or support in such a manner as to arrest the cage should it from any cause be made to descend and thus secure himself and others from possible danger; such "dogs" or supports are always to be kept in proper condition to drop in place when needed.

21. After finishing work, all daymen shall put their tools in the place provided by the mine foreman. All scrap iron and other salvaged material must be deposited in the proper place, and all working places must be kept clean.

22. All employees are requested to exercise care and economy in the use of materials and supplies; any employee will be discharged who

through carelessness or malice wastes materials or destroys the property of this company, or is found stealing or carrying away any such property.

23. Any workman offering money, liquor, or valuables of any kind to the foreman, boss, or clerk shall be subject to discharge; and any foreman, boss, or clerk accepting money, liquor, or valuables of any kind from workmen shall be summarily dismissed.

24. No person under 21 years of age will be employed in or around the mine without the consent of his parents or guardians, given on the form provided by the company for such purpose.

25. When the mine is idle no employee will be allowed to go into the mine to perform any work unless he is accompanied by an official; this does not apply to such mine officials as firebosses, safety men, or foremen.

26. All employees, upon entering the mine, shall go directly to their working places; and no person shall loiter in or about the mine, buildings, or machinery or go into an abandoned part of the mine without permission in writing from the mine foreman.

27. Employees traveling on haulage roads must take refuge in shelter holes in time to allow cars to pass them safely. Running ahead of locomotives or cars is forbidden.

28. Employees must leave shelter holes slowly after a trip has passed, must look for a red light on the rear of trip before leaving, and then must walk on the clearance side.

29. Employees must be orderly and wait in places assigned for waiting until man-trips are made up and properly placed for safe loading and the signal is given to board the man-trip.

30. No nonemployee is allowed to enter the mine unless accompanied by the mine foreman or some other official, after having obtained permission in writing from the superintendent.

31. All employees in and around the mines must receive instruction in and be competent to administer artificial respiration and to control bleeding.

32. All employees should notify a mine official of any unsafe condition they may observe in any working place, haulage road, or traveling way or any damage to doors, brattices, or stoppings as soon as possible after such conditions become known to them.

33. Every employee whose duties require him to work with an appliance or equipment of any kind should report any defects to his foreman.

34. Any person coming to work under the influence of liquor will be discharged.

35. Careless handling of explosives will result in the discharge of the employee responsible if he can be found. Failure of men working at mine faces to keep detonating caps and explosives in a place where they cannot be mixed with the coal has resulted in such material being loaded out with it, subjecting railroad, coal-chute, and locomotive employees to serious hazards.

36. Care must be taken to see that foreign material is not loaded out with the coal. Mining tools, drills, wrenches, machine bits, spikes, wood chips, track bolts, and scrap metal lost in coal will be loaded out with it and may cause serious damage to coal crushers and locomotive stoker apparatus.

37. Injuries, including those of a trivial nature, must be reported to the mine foreman before the shift is completed.

38. Safety belts must be worn by all workmen while doing repair work in or around shafts. Where a platform is being used a second safety platform shall be erected not more than two sets of timbers beneath the working platforms.

39. All trackmen, bratticemen, wiremen, motormen, brakemen, pumpers, road cleaners, or any other workmen are subject to the instructions of the foreman in charge of the section on which they are working.

40. Only regularly employed motormen shall operate locomotives, unless permission in writing is first granted by the mine foreman; this does not apply to persons inspecting or repairing locomotives.

41. Wrestling, throwing material, or "horseplay" of any kind is positively prohibited.

42. Every employee shall remain in that part of the mine in which his duties are located and shall not travel from one part of the mine to another without permission from the mine foreman or his assistants.

RULES FOR OUTSIDE EMPLOYEES, SHOPMEN, ETC.

1. Motor or locomotive pits shall be kept covered when not in use.

2. All gears, sprockets, saws, belts, etc., and all projections on revolving shafts, such as set screws, keys, bolts, oil cups, etc., shall be properly guarded.

3. All guards removed must be replaced before the piece of equipment of which they are a part is put in operation.

4. Belt shifting with the hands is not permitted.

5. Oiling of line shafting while in motion is not permitted.

6. "Horseplay" among employees is not permitted.

7. Loose clothing must not be worn by persons who are required to work around moving machinery.

8. Goggles must be worn by employees when grinding or pouring metal or when engaged in any work in connection with which unprotected eyes may be subject to injury.

9. The user is responsible for tools and their condition.

10. Tipplemen are required to have some approved device for lifting links when coupling mine cars.

11. Jumping upon loaded trips for the purpose of riding into the tipple is not permitted.

12. Tipplemen are required to watch for all defective cars and mark them for repairs.

13. No one, unless authorized by the foreman in charge, shall ride on larries, cars, trucks, carts, wagons, or other vehicles, whether loaded or empty; the operator or driver shall be held responsible for enforcement of this rule.

14. Picking coal from around coke ovens, tipples, boilerhouse, railroad cars, larries, or mine cars or burning slate dumps is prohibited.

15. All cars shall be handled and placed for loading only by regular car droppers, or persons ordered to do so by the foreman in charge, and under his direction.

16. All brakes must be inspected before starting to move cars. Always blow whistles to warn others that cars are to be moved. Always see that the derail is set to protect the main track before dropping cars down grade. Do not drop cars close to the derail, as they may be bumped off the track when the next load drops down. Do not try to drop more cars than can be controlled or more than the limit specified by the foreman; if the car brakes are found to be defective secure aid before trying to drop cars.

17. Where shifting engines are used it shall be the duty of the brakeman to ride at a point on the cars or train where he can see the engineer, as well as the track ahead, while pushing cars.

ENGINEROOM RULES

1. Hoisting engineers must be physically fit; they must satisfactorily pass a physical examination before employment and undergo a physical examination annually to determine their continued fitness.

2. The prevention of accidents to operators or employees is of first importance, and no engineer shall allow a condition dangerous to life or limb to exist without remedying the same if possible. If machinery, engine, piping, or valves are in any way dangerous and cannot be repaired at once, this fact should be reported to the master mechanic or superintendent or both at the earliest opportunity.

3. Engines should not be started, electricity, steam, or water turned on, or any material thrown, without taking precautions to see that no one will be injured by the action.

4. Men not employed in the enginerooms should not be allowed to go into them except on business, and anyone not working in the engineroom regularly shall not handle or touch any machinery or valves without first notifying the engineer in charge. The engineroom must not be used as a loafing place or dining hall by the employees working in the vicinity. Visitors should not be allowed in the engineroom unless accompanied by some authorized official or employee of the company.

5. Cleanliness in the engineroom is striking evidence of the efficiency of the engineer; every endeavor should be made to keep the engineroom clean and attractive.

6. It shall be the duty of the engineer to supervise his engine and all machinery under his charge carefully, and to see that the equipment is in proper working order before attempting to raise or lower men or material.

7. Before work is begun each morning and before men are lowered into the mine the engineer and machinist shall carefully inspect the engine, ropes, and all hoisting appliances to see that they are in a safe condition and shall make the proper report of the conditions found on blanks provided for that purpose.

8. Under no circumstances shall an engineer leave his controls while moving a trip. At the beginning of each shift it shall be the duty of the hoist engineer to operate the cages up and down the shaft at least two round trips before hoisting or lowering men.

9. When workmen are being lowered or raised the hoisting engineer shall take special precautions to keep the engine well under control, and at no time shall the speed of cages exceed 900 feet per minute or the speed of cars on slopes exceed 500 feet per minute.

10. When men are being lowered or raised at the beginning or end of the shift the hoisting engineer must have an assistant on the platform.

11. The hoisting engineer is required to refrain from conversation with any person while hoisting or lowering man-trips and under no condition allow anyone at any time to attract his attention from his engine

while hoisting. At the beginning of the shift and after stopping hoisting it shall be his special duty to inspect all parts of the engine and all appliances in connection with it, to see that they are in safe condition and in good repair. On finding any part of the engine, rope, or safety guards impaired, it shall be his duty to notify promptly the master mechanic or superintendent before starting the engine.

12. Powerhouse and hoisting engineers, head firemen in charge of boiler plants, and engineers or attendants in charge of other stationary engine rooms and washeries shall forbid all persons other than authorized employees, such as mechanics, inspectors, or foremen, in the employ of the company, from entering the engine or powerhouse rooms, unless by written permission of the superintendent.

13. Any machinist, electrician, or other person who removes any fence or part of a fence or any shielding protecting any part or parts of machinery, movable or stationary, shall replace same to the best of his ability before starting or giving orders to start the machine.

14. If the machinist or electrician is unable to repair or protect any piece of machinery properly, he shall, before starting the machine, notify the operator of the machine and also the foreman or other official in charge that the machine is dangerous.

15. It shall be the duty of every electrician, engineer, motorman, or any other employee having charge of the operation, repair, or supervision of machinery, movable or stationary, to report immediately to the attendant and the foreman or his assistant defects in machinery or safety appliances pertaining to them.

16. On finding or being informed that any machine is unsafe the foreman or his assistant shall make or have made immediately repairs of such defective machinery or parts of it; if such repairs cannot be made at that time, it shall be the foreman's duty to stop operation of the machine or part of it until such defects are remedied and the machine made safe for operation.

17. No helper, motorman, engineer, or operator of any electric machine which has become impaired shall attempt to repair the defect if it is of a nature requiring the attention of the chief electrician or his assistant. This rule applies to workmen who are competent to operate dangerous machinery but who may not have full knowledge of the mechanism of a machine or the conditions that caused it to become impaired or defective.

RULES FOR CAGERS, TOP MEN, AND BOTTOM MEN, WHERE MEN ARE TAKEN IN AND OUT OF THE MINE

1. The top cager shall be at the place assigned to him at the proper landing of the shaft before the men begin to descend into the mine at the beginning of a shift and shall remain there until hoisting of coal is

begun. He shall see that all employees have properly checked in and that not more than the number of persons permitted by law get on the cage at any one time; when they are ready he shall close the gate (if it is not automatic) and signal the engineer to lower the cage, and he shall not open the gate until the cage has been placed in position to receive the men or material. After the hoisting of coal ceases in the evening it shall be his duty to be at the proper place until all men are hoisted out of the mine. He shall see that the men get off safely and shall signal the engineer properly.

2. The top cager shall not permit any tools to be placed on the same cage with men or on any of two or more cages when persons are being lowered into the mine, except for repairing the shaft or the machinery therein; the men shall place their tools in cars provided for that purpose, and these cars shall be lowered before or after the men have been lowered.

3. The top cager shall see that no driver or other person descends the shaft with horse or mule, unless the horse or mule is secured in a suitable box or safely penned, and only the driver in charge of the horse or mule shall accompany it in any case.

4. The bottom cager shall be at his assigned place in the bottom of the shaft when the men begin to descend in the morning and shall remain there until the hoisting of coal begins, shall see that the men are safely off the cage, and then shall signal the engineer. He shall be at the proper place when the hoisting of coal ceases and the men begin to be hoisted in the evening and shall see that not more than the number of men allowed by law or company rules get onto the cage at any one time; when they are safely on he shall signal the engineer to hoist them. Before signaling to the engineer the man acting as cager during the hoisting of coal shall see that all cars are safely held on the cage by the catch provided for that purpose.

5. The bottom cager shall not allow any tools to be placed on the same cage with men, or on any of two or more cages, when persons are being hoisted out of the mine, except for the purpose of repairing the shaft or machinery therein. The men shall place their tools in cars provided for that purpose, and these cars shall be hoisted before or after the men have been hoisted.

6. The bottom cager shall see that no driver or other person ascends the shaft with any horse or mule, unless the horse or mule is secured in a suitable box or safely penned, and in any case only the driver in charge of the horse or mule shall accompany it.

7. The topman of a slope or incline plane shall close the safety block or other device as soon as the cars have reached the landing, to prevent any loose or runaway cars from descending the slope or incline plane. In no case shall the safety block or other device be withdrawn until the cars are coupled to the rope or chain and the proper signal given.

RULES FOR MINERS AND LOADERS

1. Each miner shall take special care, on entering his room or other working place, to see whether the fireboss has placed a danger mark on a prop, tie, or other timber laid across the track at the mouth of the room or entrance to the working place; if a danger mark has been placed the miner shall not go beyond it.

2. Each miner shall take special care, on entering his working place, to look for the date placed by the fireboss; if he should fail to find the mark he shall notify the mine foreman or his assistant during that day.

3. On entering his working place, each miner shall examine it carefully, take down all loose and dangerous roof rock or coal with a slate bar, and otherwise make his place safe before proceeding with his work. Safety posts and other necessary timbering shall be set before he starts to work.

4. No miner shall go to his working place in a gassy mine without first ascertaining from the fireboss that his place is safe.

5. Every miner or workman shall notify the foreman of his timber requirements at least 1 day in advance, but in case of emergency the timber may be ordered immediately; if the timber is not delivered promptly, the miner or workman shall keep away from such place until it is delivered.

6. Every miner or workman shall keep his working place at all times well-timbered and safe; he shall bar down or prop all doubtful or dangerous pieces of loose material and obey without delay all orders from his foreman in respect to these matters.

7. The miner shall keep the tracks in his working place in safe operating condition; drivers are not to deliver empty cars to miners whose tracks or timbering are not in safe or satisfactory condition.

8. No miner shall leave his working place during his shift to visit other portions of the mine.

9. Wherever traveling ways or manways are provided and kept in a safe and travelable condition all miners shall travel the manways to the exclusion of haulageways.

10. Tools, rails, drills, or other metallic material must not be carried on the shoulder, as they may come in contact with electric wires or loose pieces of roof and result in electrocution or other injuries.

11. Loaders shall securely block all cars before beginning to load coal; in addition to the brake, cars must be blocked by means of standard crossblocking by clevis on rail or other approved method, and chips or small pieces of wood or similar material under wheels will not be considered standard blocks.

12. Driving spikes, nails, files, and tools in props for use as hangers is forbidden, unless authorized by the foreman.

13. All miners and loaders, when setting props or unloading material, must provide the proper clearance from the track (at least 2-1/2 feet).

14. The roof should be tested at frequent intervals throughout the day by using the vibration method, as follows; place the finger tips of one hand against the roof and tap the roof with a pick or bar about 1 foot from the fingers; loose roof will be indicated by the feel of vibration through the finger tips. A bar is preferable to a pick for roof-testing purposes.

15. If for any cause beyond his control a miner should find his working place becoming dangerous, he shall immediately vacate the place, put a warning sign at the entrance, and report the conditions to his foreman.

16. Safety posts shall be set as soon as enough coal is removed to allow them to be placed; the safety posts should be set as soon as feasible.

17. All face posts must be round and at least 4 inches in diameter at the small end.

18. All broken posts shall be reset promptly.

19. Miners are not permitted to remain at the face of the working place while the machine is cutting.

20. All miners shall have enough tools to enable them to do their work properly and safely; in this mine the following tools are required at the working place: Shovels, picks, sledge, wedge, drill, slate bar not less than 4 feet long, axe with handle not over 18 inches over-all, and saw.

21. All miners, loaders, machinemen, and company men must wear goggles when picking or shoveling coal or rock; this includes such work as brushing top or taking up bottom, breaking rock, and cutting hitches and holes for crossbars. Machinemen must wear goggles when setting bits.

22. When cleaning up for the cutting machine at the end of the shift, each miner and loader must see that his place is properly "squared up" and ready to be cut. All loose dirt and slate must be picked up and moved back out of the way.

CAUTION WHILE WORKING IN PILLAR SECTION

Every employee engaged in pillar work must use extreme care to protect himself and others from the dangers incident thereto and must bear in mind that the coal he removes weakens the roof and makes frequent roof inspection necessary. Every employee in pillar sections must pay particular attention to the condition of the roof over the break-throughs, haulageways, and passageways in the vicinity of such pillar work, immediately correct any unsafe condition or put up warnings, and thereafter notify the foreman or his assistant at once.

TIMBERING RULES

1. Special attention is directed to the timbering or removal of unsafe roof or of coal that has been undermined; and every employee must take the necessary precaution to safeguard his working place from overhanging loose material as soon as a dangerous condition is observed by him or called to his attention.

2. Every miner is reminded that all overhanging strata and coal which has been mined by hand or undercut with a machine must be watched. He is required to set enough blocks, sprags, or timbers when mining or cutting coal, or when working in places where coal has been mined or cut, to protect himself from falls of roof and coal.

3. The miner must not do any work other than to correct unsafe conditions until the dangerous place has been made safe. If for any reason the necessary timbers for making a place safe cannot be supplied when requested, the miner shall vacate the place until the necessary timbering is supplied, and no employee shall work in any place until he has props and timbers sufficient to make and keep it secure.

4. All timbering in working places must be installed in accordance with the standard adopted by the company. The standard calls for the minimum requirement, and additional timbers should be placed when necessary.

5. If the roof in a working place is of such tender character that it cannot be made safe with props, the miner must vacate the place until it can be made safe with proper crossbars and lagging, or otherwise.

6. The roof and overhead strata must be supported by temporary posts or blockings and other precautionary measures taken for protection from injury while setting crossbars or while taking down loose rock.

7. In pillar pulling, breakline posts shall be maintained at all times at the loose ends of pillars and stumps.

8. While undercutting coal, particularly were places are wide, where there are slips in the coal, or where the overlying roof is bad, miners shall set sprags or temporary props under the coal to protect themselves from probable falls of coal or roof.

9. Cap pieces at least 2 inches thick, 18 inches long, and as wide as the post shall be used on all posts.

10. All timbers for a room must be stored in some crosscut of the room, where possible.

11. In setting props, the foot of the prop must be put on the hard bottom and the prop set square with the roof and bottom.

12. Special care must be taken when recovering temporary or safety posts; they should not be removed until substitute or possibly permanent timbering has been installed.

13. The removal of timbers in pillar workings must not be attempted, except by specially designated employees or in the presence and under the direct supervision of the foreman or one of his assistants.

14. A proper type of slate bar should always be used when taking down slate or rock; the use of a pick for this purpose is prohibited.

15. When taking down slate or rock, the miner shall protect himself fully by timbering adjacent to the rock to be taken down and assure himself of an unhindered line of retreat.

BLASTING AND CARE OF EXPLOSIVES

1. No employee shall take into the mine a larger quantity of explosives than may be required for a shift, and at no time shall more than 5 pounds of explosives and more than 7 detonators be kept inside the mine by any employee, except on written permission of the mine foreman.

2. The company sells permissible explosives and the proper detonators for use with them. No employee shall take into the mine or use any explosive or means for firing it except that supplied or approved by the company.

3. Explosives and detonators must be carried and kept in a safe receptacle approved by the superintendent and must be stored separately in cubbyholes in the rib at least 10 feet apart and at least 75 feet from the working place.

4. No shots shall be fired in any place known to liberate explosive gas until such place has been properly examined by an authorized and competent person and found to be free from explosive gas.

5. No charge of explosive in any one shot shall exceed 1-1/2 pounds, and not more than one shot shall be fired at a time.

6. All holes must be tamped to the collar of the hole with clay or other incombustible material, using a wooden stick.

7. All shots shall be fired by electric detonators and approved battery.

8. After a shot has been fired, the miner before starting work shall carefully examine the condition of the roof and its safety.

9. The assistant foreman shall be notified promptly of misfires, and no person shall return to the working place where a misfire has occurred until given permission to do so by the assistant foremen, who will personally direct the drilling and charging of another hole.

10. No miner or other employee, except as specially designated by the miner foreman, shall drill out or attempt to drill out or make any effort in any manner whatsoever to remove any failed shot.

11. No person shall return to a missed shot lighted with a fuse until the following day. No person shall return to a missed shot fired by electricity until all wires are disconnected from battery or power line and at least 10 minutes has elapsed.

12. No coal shall be shot off the solid except by permission of the superintendent, and then only in a hole which is not drilled "on the solid" (that is, the distance from the back of the charge to a free face is less than the depth of the hole).

13. Drill holes shall be placed according to the established standard, and no hole shall be drilled on the solid; rib holes shall parallel the line of sights and shall not "grip" the rib.

14. Holes in coal less than 2-1/2 feet deep shall not be shot without special permission from the mine foreman.

15. Under no conditions shall two different kinds of explosives be used in the same hole.

16. All drillings must be removed from the hole before it is loaded; each miner must provide himself with a scraper for this purpose.

17. In tamping holes no miner shall use a dummy or cartridge of stemming longer than 12 inches.

18. One dummy or cartridge of stemming not less than 6 inches long must be placed in the hole against the explosive before tamping is started.

19. No miner shall drill or load a hole in any working place before the place is cut.

20. All "bug" dust must be removed from the kerf and loaded out of each working place before shots are fired.

21. The amount of explosive to be used in any rock hole shall be at the discretion of the mine foreman, and it shall be the duty of each employee to ascertain from the foreman the proper amount of explosive to be used in rock shots before loading.

22. It shall be the duty of every miner and others firing shots to give an alarm by shouting "Fire"; also to guard entrances of places where shots are being fired until such shots have gone off.

23. Miners must not drill holes and clean "bug" dust from the cut while the mining machine is cutting across the face.

24. Where the firing of shots is restricted to a specific time, no miner shall fire a shot until the time appointed for him to do so and then only in such rotation and at such intervals as designated.

25. At any place where pillars are thought or known to be less than 10 feet thick, miners must notify those in the next room before firing.

26. After a shot has been fired and before work is resumed, the miner shall carefully examine the condition of the roof and its safety.

27. No hole or shot shall be fired which depends for its action on any other hole or shot fired at the same place at the same time; in other words, dependent shots shall not be fired.

28. Shots are not to be fired unless the place is timbered according to standard.

29. Holes shall not be loaded when too small in diameter to allow the charge of explosive to be easily pushed to the back of the hole.

30. Cables used for firing shots shall be at least 100 feet long, of insulated wire free from bare spots and bare splices; the end of the wire used to make contact with the shot-firing unit shall be so protected as to prevent premature shots caused by accidental contact with batteries, feed wires, rail, pipe lines, or other possible conductors of electric current.

31. The blasting cable shall be kept away from the track and should be supported on rib or timber where possible. The wires at the firing end of the blasting cable shall at all times be kept twisted together or short-circuited, except when shots are being fired.

32. Only a wood or copper punch shall be used in making holes in explosives for detonators.

33. Where two or more men are working together and blasting electrically, one man shall do the blasting, while the man making the shot at the working face shall keep the blasting unit in his possession.

34. Where shot firers are employed, each miner must notify the shot firer in person and flag his shots in order that the shot firer may not overlook any shots.

35. Bulldozing, such as mudcapping, will not be permitted in the breaking of rock; in breaking rock, holes must be drilled in the rock for blasting.

36. The wrappers must not be removed from explosives.

37. No one, other than those required for the "job", shall be near explosives while they are being transported or stored, or during blasting.

38. Rapid firing of nearby shots, dependent or not dependent, is prohibited. The time between the firing of nearby shots shall be adequate to permit the ventilating current to dilute properly any inflammable gas present, and the noxious gases of the explosion of all previously fired nearby shots.

RULES FOR SHOT FIRERS

1. Only authorized persons certified by the State Department of Mines shall be employed as shot firers. When on duty shot firers must be provided with permissible flame safety lamps, in good order and lighted.

2. No shot shall be fired while explosive gas is present in any place.

3. Shot firers must always return to the face with their flame safety lamps after firing a shot to examine the place for fires, loose roof, and gas, and to repair or replace any damaged brattice or other ventilation device or equipment.

4. In firing shots, only rubber-covered cable will be used; this cable must be kept reeled at all times, except when actually in use.

5. All shots must be tamped to the collar with clay or other incombustible tamping, and under no circumstances shall coal dust or other combustible material be used.

6. In any place where two or more shots are to be fired, wherever there is a dependent shot--that is, the result of the shot depends upon the action of the preceding shot--the dependent shot must be fired singly and not in rapid succession.

7. Shot firers shall refuse to fire any shot which in their judgment is not properly placed or charged in a workmanlike and practical manner; they shall also refuse to fire a shot until adequate timbering, proper removal of "bug" dust, proper blocking of cars, and other safe measures are in effect.

8. Nothing but a wooden tamping rod shall be used in tamping holes.

9. Shot firers shall see that every one is in the clear before firing a shot and that all approaches are guarded. When a break-through into another room or entry is about to be made by blasting it shall be the duty of the shot firer to warn the workers to leave the adjoining place and to see that the place is properly guarded before the shot is fired.

10. No shot shall be fired if the charge is too close to a free face; this applies particularly to slabbing shots and when "holing through" to previously mined regions.

11. Each shot firer shall examine the record of shots fired by the shot firer preceding him and familiarize himself with the location of any missed shots. He shall not allow missed shots to be handled in any way, either by attempting to remove the tamping, pulling out the wires, or in any other manner, except by drilling a new hole not closer to the missed shot than 2 feet at any point.

12. After drilling a hole parallel to a missed shot and firing it a shot firer shall remain to see that all the explosives and detonators are recovered from the missed hole.

13. When electric detonators are used and a shot fails to explode, no employee shall return to the place until enough time (not less than 10 minutes) has elapsed to be sure of the absence of danger. If a shot fails to explode the shot firer shall guard against entrance of any person into the place until enough time has elapsed to return with safety; otherwise he shall notify all employees in the vicinity, placing warning signs at all entrances to the working place.

14. A hole must not be tamped and shot unless it is at least 6 inches from the clear at the back of the machine cut and at least 6 inches from the solid rib.

15. Shot firers shall report all unsafe conditions to the mine foreman when ordinary measures of timbering and taking down rock are inadequate to secure the place; this applies on entries and slopes within his district as well as in the rooms and crosscuts.

16. Shot firers shall refuse to shoot any shots in hand-loading places until all "bug" dust has been removed from the kerf and loaded out and shall refuse to shoot any shots in machine-loading places until the "bug" dust has been removed from the kerf and thoroughly watered to a consistency that will mold in the hand or until it has been loaded out.

17. Before attempting to load or tamp any hole shot firers must see that all electric power has been cut off the place.

18. All shots must be fired by regular permissible shot-firing units furnished for this purpose and in no instance from machine or trolley wire, lamp battery, or dry cell with live exposed terminals.

19. Every shot firer must report daily in the shot firer's report book all defects in wire or water lines, missed shots with cause of failure and location of shot, and any violation of the rules set forth herein.

20. The placing or firing of a bulldozing or mudcap shot will be considered sufficient ground for discharging the offending employee.

21. The shot-firing cable shall be a No. 14 rubber-covered cable, at least 100 feet long, and shall not be used for any purpose other than shooting. Cables should be regularly and thoroughly examined to see that

they have no breaks or bare spots, and should be kept reeled at all times, except when strung out for use, and should be so placed as not to come in contact with light or power wiring, steel rails of track, mine cars, pipe lines, or any other metal objects that might act as a conductor of electric current.

22. The cable ends attached to the shot-firing unit shall be "shorted" at all times except when firing shots, to eliminate the possibility of a stray ground or other current causing a premature explosion.

RULES FOR MACHINE RUNNERS AND HELPERS

1. It shall be the duty of the machine runner to see that his machine is in good repair and well lubricated. Mechanical defects which the machine runner cannot repair himself shall be reported at once to the machine boss or mine electrician.

2. It shall be the duty of the machine runner to take every precaution to prevent injury to his machine from falls of roof or rib.

3. The machine runner must examine carefully, the place that he is to cut, for loose slate or other unsafe conditions and must not cut such a place until it is made safe. In mines where gas is likely to be encountered he must test for gas with a permissible flame safety lamp; if the presence of gas is detected, he must not operate the machine until the gas is removed and the place is pronounced safe. A cutting machine shall not be operated in any gaseous mine more than 30 minutes without an examination for the presence of gas; if gas is found the operator shall immediately stop the machine and cut off the current, and the machine shall not be started until the gas is removed and the place pronounced safe.

4. Mining machines shall be so placed for each cut that the least possible amount of coal may be left under the cut and the machine crew must sprag all coal where necessary.

5. The machine runner must not permit visiting in any place in which the machine is being operated; under no circumstances shall machine cutting be done with only one man present.

6. All machine cuttings or "bug" dust shall be cleaned from beneath the cut, from over the cut, or from the shear, as the case may be.

7. The machine runner and helper must inspect carefully the roof, sides, and face of each working place before beginning work, and, if any evidence of weakness is found, additional timbers must be set and replaced as the machine is moved across the face, in order to protect themselves, other employees, and equipment from injury.

8. The machine runner must not permit any employee on the machine while traveling in the mine.

9. In order to prevent injury to the machine runner by reason of insecure position of the machine jack, the helper is instructed to hold the jack in position, and the machine runner is advised to see that the helper observes this precaution until the runner has moved to a position where the jack in falling will not injure him.

10. The machine runner must see that the machine bits are set to gage at all times; dull bits shall be changed as required.

11. If at any time the machine or machine cable requires repairs by the runner, the helper shall first remove the electrical connection from the machine and the power circuit, and shall keep the connection in his possession until such repairs have been completed and the machine runner instructs him to replace the connection; it is advisable to have an extra cable at hand and to send any defective cable to the surface where safe and proper repairing can be done.

12. The machine runner's helper shall guard against the swinging of the mining machine when the jacks are tightening at the time the machine starts cutting.

13. No employee shall pass over the cutter bar of the mining machine at any time, but must pass around the rear of the machine.

14. Machine runners must stay at the rear of the machine at all times, as nearly as practicable, while it is cutting coal, and must remain at the rear of the machine until it is sumped at least 2 feet in the coal. When necessary to go to the front of the machine, the machine shall be stopped and bit clutch disengaged.

15. Machine crews are required to reset all timbers knocked out by them.

16. The helper must travel at least 50 feet in advance of the machine when it is traveling on main haulage entries.

17. The mining machine must be stopped before the jacks are changed.

18. The machine runner and helper as far as feasible must see that all metal parts, tools, bits, and scraps of iron are kept out of the coal to avoid loading them out with the coal.

19. From time to time during the progress of their work, the machine runner and helper must examine the working place to see that it is not becoming unsafe; if in the progress of their work it is necessary for them to remove timbers which have been set to secure the roof, they shall set additional timbers necessary to protect themselves and the machine from injury. Should unsafe conditions arise which they cannot correct, they should suspend work and, if safe to do so, remove the machine to a safe place, and notify the mine foreman or his assistant.

20. The machine runner shall be within reach of the starting box at all times while the machine is running. The jacks and ropes or chains must be examined from time to time while the machine is running to keep them tight and secure. The machine runner shall keep careful supervision over the machine, examining particularly the electric connections, oiling system, and starting box; should any defects be discovered which make operation of the machine unsafe, work with it should be discontinued until the defect has been repaired, or the mine foreman or his assistant or other person designated by the mine foreman is notified.

21. The machine runner shall examine daily his trailing cable for abrasions and other defects, and he shall also carefully observe it while in use, and shall repair any defects or if unable to do so, he shall promptly give notice to the mine foreman or his assistant or someone designated by the mine foreman; he should see that the cable is so placed as not to be injured and not to interfere with or endanger the travel of employees, mine cars, motors, or live stock.

22. Extreme care should be used in moving machines from place to place. The machine runners and helpers shall report to the mine foreman or his assistant all dangerous conditions of roof or track of which they have knowledge.

23. Machinemen, helpers, and other employees shall not throw coal dust or coal into the gob.

24. It shall be the duty of the machine runner to "run centers" before sumping and mark the place plainly on the roof. Machine runners will be held responsible for both the alignment and the width of the working place.

25. Machine runners must learn from the fire boss each morning about the condition of all working places on their "run."

26. Machine runners must not sump the machine in high gear.

27. A mining machine shall not be left standing near or under a canvas curtain.

28. When mining machines are sent to the outside for repairs, runners must remove all bits from the cutter chains.

29. Machinemen shall not wear loose clothing; trouser legs must be worn inside of high shoes, leggings, or sock legs, and jumper inside of overalls. Rubber shoes and short wrist gloves should be worn.

30. Mining machines shall not be loaded or moved unless they are equipped with a safety chain or other approved device, applied so as to prevent the cutter chain from revolving.

31. Coal-cutting machines shall not be operated for undercutting coal without water attachment in use. A machine without water attachment but otherwise in good working order will be considered out of order and must not be operated.

32. The runner or helper shall not stand on any part of the truck when loading or unloading the machine.

33. The machine runner or helper shall not work around the cutter head when the bit clutch is engaged. He shall not use a bar to raise the machine from the side in which the under-frame has been cut out to free the slack while the cutter chain is in motion.

34. The machinemen shall set safety posts while cutting through pillars or stumps and shall reset all timbers displaced by them.

35. The machine runners shall not proceed around curves with the machine until the helper has gone ahead and ascertained whether conditions are safe.

36. The machine runner shall put the reverse lever in neutral position whenever he leaves the machine.

37. The machine must be loaded on a truck and stored in a safe location at the end of the shift. It must clear the frog on haulage roads by at least 10 feet. The cable must be disconnected from the trolley wire and rail and completely reeled in.

38. The machine must not be left or stored where it will interfere with or obstruct the ventilating current.

39. Machine runners must not tamper with any permissible parts of approved mining machines.

40. Machine runners must use only the standard fuse as designated by the electrician.

41. The guards must be kept in place at all times on mining machines equipped with cutter-bar guards.

42. Machinemen will be held responsible for all tools required for their machines; they shall also be held responsible for the condition of the tools, particularly the points of jack bars, which must always be kept pointed.

43. Machinemen shall be held responsible for the care of the machines while in their charge, in accordance with the instructions of the mine electrician. In making examinations or repairs, they shall be governed by the rules and regulations related to such work.

44. The machine runner must oil the cutter chain immediately after cutting each place.

45. Machines shall not be braced with rails or other substitutes, but jacks and ropes must be used in the proper manner while cutting.

46. Mining-machine cables, drill cables, and jackhammer cables must be hung over room tracks and switches, and cable should never be placed in frogs and switches.

47. When a timberman is employed to timber for machines, a machineman must not cut a place without his assistance.

48. A coal-cutting machine must not be operated while undercutting the coal unless it is equipped with safety ground wires. A machine not equipped with safety ground wires in good order will be considered out of order and will not be operated.

49. Machinemen must hang cables inby the switch and pass them under the track at room switches.

50. The practice of moving mining machines at the face by what is known as "walking the bits" is prohibited.

51. Machinemen must not cut any place unless the miner is away from the face and to the rear of the machine.

52. Mining machines must not be used for moving cars.

RULES FOR MOTORMEN AND MOTOR BRAKEMEN

1. All locomotives shall be inspected each morning, and they must not be removed from the motorbarn unless they are marked "O.K." with the appropriate date.

2. Motormen shall be responsible for the care of locomotives in their charge and see that they are well-lubricated and in good condition at all times.

3. All mechanical or electrical defects shall be reported to the mine electrician or master mechanic; any indications of low voltage on the line should be reported promptly to the mine electrician.

4. Mine locomotives must be operated at a reasonable speed and kept under full control at all times; under no conditions shall the load or speed limit specified by the mine foreman be exceeded.

5. Each motorman shall make careful note of the condition of the haulageways over which he operates and report to the mine foreman any dangerous or unsafe place or condition, such as defective timbering, wiring, or bonding.

6. Whenever a motorman leaves his locomotive he shall remove the trolley pole from the wire; if, however, there is some accident to locomotive operation, such as a derailment, and it is necessary for the motorman to leave his equipment to flag or seek assistance, the trolley pole may be left on the wire to provide power for headlights to warn other employees.

7. Motormen shall stop their trips to throw switches, unless trolley-line switches are automatically controlled by trolley clips or otherwise.

8. Motormen shall see that there is a conspicuous light on each end of main-line trips at all times.

9. Motormen are required to have a gong and a headlight in good condition on their locomotives at all times.

10. It will be the duty of the motorman to give warning with his gong when approaching persons, animals, doors, sidetracks, or curves on haulageways.

11. Motormen will see that the sand boxes are filled and the sand pipes clear.

12. Motormen and brakemen are positively prohibited from alighting while the locomotive is in motion to throw switches, to open doors, or for any reason except to protect themselves or others from injury in case of obstruction or derailment.

13. Motormen will not allow anyone to ride in the locomotive or on trips except those specially authorized to do so.

14. Making flying switches is prohibited.

15. The locomotive and all cars on a trip shall come to a full stop when attempting to couple or uncouple.

16. All motormen and brakemen are forbidden to make a coupling while standing on or between the bumpers of cars or locomotives.

17. Back-poling by motormen will not be permitted.

18. When two or more locomotives are going into or out of the mine, they shall be kept at least 300 feet apart and under complete control within the authorized space limit.

19. Brakemen will not be permitted to ride the front end of a light locomotive.

20. Motormen must not attempt to oil locomotives, open sand pipes, adjust headlights, or do any other repair work on locomotives in motion.

21. No employees are permitted to couple or uncouple cars except designated motormen and brakemen, unless instructed to do so by the foreman.

22. Cars must not be pushed by main-line locomotives except at side tracks and tipple approaches or for the purpose of coupling cars.

23. Pushing trips by gathering locomotives, except by local shifting, is prohibited if it is possible for the trip to be pulled. Whenever empty trips are pushed, trip riders must ride inside of the front car and the motorman must sound the gong while moving the trip. There must be an efficient trip light on the rear end of all made-up motor trips and on the front end of all motor-pushed trips.

24. Cars with defective brakes or otherwise in bad condition shall be removed from service immediately and not reinstated until fully repaired.

25. Brakes must be set on all cars when standing on a grade.

26. One or more empty cars must be placed between the locomotive and a car hauling rails, pipes, or similar material.

27. A motorman shall not get off his motor without closing the control and shall not move the locomotive without being seated in the cab.

28. No one is permitted to ride between cars on any trips whatsoever. Motormen and brakemen must not wear loose clothing; trouser legs must be worn inside of high shoes, leggings, or sock legs and jumpers inside of overalls. Rubber shoes and short wrist gloves shall be worn.

29. Motormen shall not move trips until given the proper signal by brakemen.

30. Motormen shall not place the trolley pole on the wire while standing by the side of the locomotive; they shall see that the controller is on the "off" position and the brake set before placing the trolley pole on wire.

31. The motorman shall not leave the locomotive unless the light is burning brightly on at least one end, the reverse lever in neutral position, and brakes set securely and some approved device is used to prevent the brakes from unwinding.

32. Motormen and brakemen must give special attention to materials ordered and must deliver them promptly.

33. Motormen or brakemen must not leave ventilating doors standing open while placing or gathering cars.

34. Motormen or brakemen shall not leave locomotives or trips standing where they will interfere with or obstruct the ventilating current.

35. Brakemen will be held responsible for replacing all derailers and safety blocks when the trip or locomotive has passed through them.

36. Brakemen shall not run along the tops of empty or loaded cars.

37. The brakeman shall ride in the rear car of every man-trip.

38. Motormen shall not pass a red signal light; if signal lights will not burn, a motorman should send his brakeman ahead at least 100 feet to act as flagman.

39. Motormen must not run past places where regular flagmen are employed and where block signals are used without first getting the clear signal. No other signal shall be the same as the stop signal.

40. Locomotive crews are especially warned of the danger of touching the trolley wires or electric cables in the mine.

41. All haulage employees wearing electric cap lamps shall conceal the cables of their lamps under their clothing to prevent them from catching on cars or other equipment.

42. After delivering empties into an entry motormen shall see that the track is clear before starting out and shall proceed with their trips under full control at all times.

43. Motormen must keep their trips under full control when approaching yards or any dangerous places, or while traveling over trestles or bridges.

44. "Bucking" cars or locomotives on the tracks is positively prohibited; the presence of a bucker on a motor or trip is a violation of the rule and will subject both motorman and brakeman to discipline.

45. All locomotives shall be equipped with rerailers, and the motormen shall be held responsible for them.

46. Switch points shall never be held in position with the hands while a car or cars pass over the switch; if the switch is out of order, the points should be spiked over or held over with a stick so as not to endanger the hands.

47. The practice of "nipping" is hazardous and will not be permitted.

RULES FOR DRIVERS

1. Drivers must get their animals at the stable and be ready for work at the time and place appointed. Running of stock to and from work will not be permitted.

2. Drivers must take proper care of their animals, feeding and watering them at eating time, and also take necessary precautions to keep them from being injured. They must not strike animals with anything but such whip or strap as the mine foreman allows; cruelty to animals will not be tolerated under any circumstances.

3. Should any sickness or accident occur to his animal, the driver will at once report it to the driver boss or stable boss. Damage to animals occasioned by the carelessness of drivers, or in any unaccountable way, will be considered sufficient cause for suspension or discharge.

4. Drivers must close all doors promptly when placing or gathering cars; leaving doors propped open, when the door is supposed to be held closed, will subject the offender to discipline.

5. If any door, brattice, or stopping is displaced or not operating properly on his section, the driver should report the fact immediately to the fireboss or the mine foreman.

6. When cars or trips are traveling down grade great care must be taken to keep them under control at all times and prevent them from running upon the drivers or animals.

7. When drivers have occasion to leave cars or trips, or when cars or trips are stopped, except at the regular station, they must see that the cars are left in a safe place secure from collision or other danger, protecting drivers or approaching motormen; if a car or trip is left in the main haulageway the driver must go back and notify approaching drivers or motormen of the obstruction.

8. Drivers shall carry and deliver to the working places with all possible dispatch and in the manner prescribed by the mine foreman mine timbers, rails, or other necessary materials. If for any reason they cannot obtain the material ordered the fact should be reported to both the workmen and the mine foreman.

9. Drivers should not attempt to couple cars until all cars have come to a full stop; they shall be particularly careful to see that no attempt is made to couple moving cars on curves.

10. Drivers shall take their animals back to the stable after completion of the day's work and must not leave them in the mine at any point unattended unless they are securely tied. The manway must be used in taking animals into and out of the mine, and drivers must accompany their animals.

11. Drivers shall report at once to the mine foreman any place along their territory where there is not fully 30 inches of clearance from the rail and where there is any obstruction on the working side.

12. Drivers shall not permit anyone to ride on cars without permission of the mine foreman.

13. On runs designated by the superintendent or the mine foreman drivers will be held responsible for carrying a red tail light on the rear end of each trip, the tail light to be left in place until the trip is disposed of.

14. Drivers shall not ride on the front end of loaded cars but when conditions require may ride on the front end of empty cars.

15. Drivers must accompany each car to and from the working face.

16. Drivers unfamiliar with the haul assigned them shall not drive on it until instructed by the foreman or some person delegated by the foreman how to operate with safety.

17. Drivers shall see that no cars are left standing nearer than 8 feet from either side of a curtain.

RULES FOR ROPE RUNNERS

1. The rope runner will take charge of the slope during the working hours, reporting promptly to the mine foreman any defective condition, such as in timbering, ropes, tracks, rollers, or signal wires.

2. Before starting work in the morning, he shall inspect the ropes, sockets, and rope couplings and sign a report on forms provided for the purpose that this has been done.

3. The rope runner shall be on the alert constantly during the day to inspect each trip as it leaves the parting for defective hitchings; if one is found it must be replaced immediately or the car must be switched off until it can be brought to the surface singly, effectively secured by wire rope or otherwise; under no circumstances shall it be brought out on a regular trip.

4. He shall see that no person is allowed to interfere with the signals.

5. He shall be held responsible for allowing any person, except the proper mine officials or men engaged in repair work, to travel or be on the slope during working hours.

6. He shall permit no one to ride loaded or empty trips except at times devoted especially to man-trips, except as specifically ordered by the mine foreman.

7. Runners shall report at once to the mine foreman all places where in their judgment additional refuge holes are necessary.

8. Trips must not be left hanging on panel or main slope ropes.

RULES FOR MAN-TRIP

1. All man-trips shall be handled with caution, and every trip shall have an official in charge to make certain that it is operated safely.

2. Man-trips shall come to a full stop before anyone gets on or off.

3. Standing up or changing from one car to another while trips are in motion will not be allowed.

4. All men shall ride on the off side from the trolley wire.

5. All tools must be placed in the first or last car of the man-trip.

6. The speed of a man-trip shall be directed by an official in charge and shall at all times be slow compared with the handling of other trips.

7. Man-trips will leave the outby terminal in time for the men to be at their working places at the stipulated starting period for the mine.

8. No man-trips other than regular trips shall be run, except on orders from the mine foreman, or in case of an accident.

9. Men shall board and leave the man-trip in an orderly manner, without haste or crowding, and on the side opposite the trolley wire.

10. Overcrowding in cars and "horseplay" on man-trips will not be tolerated.

11. If there is limited clearance at any point, men must sit low in cars and should keep arms inside of cars.

RULES FOR FIREBOSS

1. Before entering the mine, the fireboss shall examine his flame safety lamp carefully to see that it is properly assembled, filled, trimmed, and in a safe working condition and securely locked; he shall use a permissible safety lamp supplied by the company.

2. He shall see that the ventilation apparatus is working properly and note whether readings on the water gage indicate normal conditions underground.

3. It shall be the duty of the fireboss to examine carefully all working places not more than 2 hours before the beginning of each shift. He shall mark in chalk on the face, or on the prop nearest to each face examined or in other suitable manner his initials and the day of the month and the month and year. If gas is found a danger board, "GAS - KEEP OUT", shall be placed at all entrances to such place and at a safe distance from the gas; if the gas is found in a room, a danger board must also be placed on the entry outside or on the intake side of such room.

4. Preferably no accumulation of gas with gas percentage above 5 percent shall be moved on the working shift; and certainly no gas accumulation shall be moved on the working shift if the amount of gas is of so large a quantity as to make possible the raising of the gas concentration in the air current with which it is moved above 1-1/2 percent.

5. After making his examination the fireboss shall station himself at the mouth of the mine, write a report of his findings, indicating with red ink where gas is found, and tell each man before he enters the mine the condition of his working place and whether or not he may enter it.

6. The fireboss shall then re-enter the mine and immediately take measures to safeguard or to remove by ventilation all gas he may have found during his first examination and extend brattices so gas may not accumulate. It shall be the duty of the supervising official while removing gas to prevent any one except those duly authorized to enter or remain in any part of the mine through which the accumulation of gas is being passed, and that all electric power lines or electric machinery are "dead" before the gas is carried into contact with them by the ventilating current.

7. The fireboss shall send out of the mine any man who fails to learn the condition of his working place before entering the mine, who enters the mine without his identification check, who injures or changes any brattice without making a report, or who is known to have done any act which may endanger his own safety or that of his fellow employees.

8. The fireboss shall examine all accessible abandoned or inactive places and all stoppings at least twice each week, noting the result of the examination in his report book.

9. It shall be the special duty of the fireboss at all times to see that the air is moving in proper volume and to locate falls in the airways and remove them if possible; should the fall or falls be too large for him to remove personally he will notify the mine foreman, who shall assign a sufficient force to remove them as speedily as possible.

10. The fireboss shall report to the mine foreman any places, either in rooms or headings, which are not properly timbered and dangerous to workmen from falling rock or coal while in or passing under such places.

While making his examinations he shall note all defects in ventilating apparatus, roadways, pipes, electric cables, or wires, and any dangerous condition of timbering and report all findings to the mine foreman. He shall see that all dangerous roof is safely propped or taken down and that no employee is unnecessarily exposed to danger of any kind.

11. The fireboss shall order from the proper person such material as brattice cloth, lumber, timber, etc. necessary to keep all places safe.

12. The fireboss shall be on the lookout for evidence of barometric changes, using extra caution when excessive atmospheric disturbance is indicated.

13. When not using an electric cap lamp every fireboss shall carry a flashlight. If a fireboss's safety lamp is extinguished he is required to return by the aid of a flashlight to the most recently examined clear place and then light his lamp, using only the proper igniter within the locked lamp.

14. When the fireboss finds the ventilation interrupted by an open door, broken door, or other cause he will not correct the condition until he knows the probable effect of so doing; after finding that the other sections are clear of gas and that no danger need be expected by repairing the faulty condition he can restore the ventilation; then the affected sections must be reexamined to ascertain that the places are clear of gas.

15. It shall be the special duty of the fireboss, while making inspections through old workings, to take notice particularly of the ventilation, and he should make note of such safety factors as the accumulation of dust and dried-out timbers and report his findings and suggestions to the foreman. He shall also investigate and report to the foreman the location and nature of new falls, whether the territory beyond is accessible or inaccessible as the result of falls, and any noticeable effect on the ventilation.

16. Only a competent and certified man shall remove gas; in all cases where a large quantity is discovered the gas should be removed under the supervision of the mine foreman while the workmen are out of the mine.

17. The fireboss shall inspect the electric switches while making his first examination of the mine. He shall also indicate in the record book what switches he has inspected and whether they were found open or closed.

RULES FOR MINE FOREMAN AND ASSISTANTS

1. It is the paramount duty of the mine foreman to know and to observe carefully the mining laws of the State and the rules promulgated by the company for avoiding injury to the employees, and to require strict observance of such laws and rules by those under his supervision.

2. The mine foreman is empowered and it is his duty to exercise thorough supervision over all working places, and

_a_. To report to the district mine inspector any violations of the mining laws for prosecution in accordance with the provisions of such laws;

_b_. To provide and have delivered to working places an adequate supply of materials needed for safe operation, such as mine props, caps, wedges, and timbers;

_c_. To instruct all inexperienced employees in safe practices and methods;

_d_. To prevent reckless conduct by the employees in the performance of their work;

_e_. To require strict obedience;

_f_. To enforce rigid discipline.

3. The mine foreman or his assistant shall direct the working forces in the mine, visiting each working place at least once each day and posting his initials, the date, and the time of his visit. He shall maintain proper discipline and take available precautions for the safety of the men in his employ, as well as for the property and other interests of the company.

4. The mine foreman shall direct the miners to prop their working places securely and shall personally see that all dangerous conditions are either removed or made safe; if, for any reason, he cannot personally or otherwise definitely supervise the work in making the place safe, the men must be removed from that place.

5. The mine foreman or his assistant shall see that all break-throughs are driven at proper distances and that the ventilation of the mine is kept in safe and healthful condition.

6. The mine foreman shall see that all machinery under his control is properly guarded to prevent clothing or body of any person from being caught in such machinery; wearing loose clothing is prohibited.

7. The mine foreman or his assistant shall investigate every case of personal injury, ascertain the facts, and report on the proper form within 24 hours; when an accident occurs every possible precaution shall be taken to prevent a recurrence.

8. It shall be the duty of the mine foreman to see that all safety devices and fire-fighting apparatus are kept in working order at all times; to see that oily waste and other refuse are not allowed to

accumulate where they might cause fire; and to see that metal cans with self-closing tops are provided in all places where such material is likely to accumulate.

9. It shall be the mine foremen's duty to see that all stretchers and first-aid equipment are in their designated places, that first-aid boxes are kept well-supplied at all times, and that stretchers and similar equipment are in first-class condition.

10. All return aircourses must be traveled by the mine foreman or his assistant at least once each week; and evidence of the inspection, showing date and initials of the official making the inspection, shall be left at conspicuous places. A record book shall be kept in the mine foreman's office showing that this inspection has been made, by whom, the date, and the condition of the aircourses in the mine, as well as the measures taken to keep them safe and effective as air carriers.

11. The mine foreman or his assistant shall give courteous attention to any employee who reports a dangerous condition existing in or around the mine and shall note the same in writing; he shall investigate the reported condition at the earliest possible moment and correct any defects found.

12. The mine foreman or his assistant shall read the written report of the fireboss or see the fireboss to ascertain the condition of the working places at the beginning of the shift; he should countersign the report before entering the working parts of the mine.

13. The section foreman is the representative of the mine foreman, who is his direct superior and to whom he is responsible; the section foreman is responsible for every condition and action occurring on his section and shall immediately report to the mine foreman any condition or circumstance which he cannot promptly correct or control.

14. The section foreman must conduct himself in a manner to command and retain the respect of his fellow workers. His duties are many and, in a general way, are summed up in this and the preceding paragraph, but a partial detailed list is as follows:

New men.- The section foreman shall instruct new men regarding company rules; tools required; methods of mining, timbering, blasting, laying track, peculiarities of seam, dangers encountered, etc; observe men for loose or dangerous clothing; and place inexperienced men with experienced men.

Man-trips.- The section foreman shall take charge of the man-trip to and from his section; shall see that enough cars are supplied to permit proper seating, see that cars are attached to the "motor" by a high-quality insulated coupling, and see that speed does not exceed 6 miles per hour.

Duties at working place.- The section foreman shall inspect each working place at least twice each shift, leaving evidence of his visits by proper marks, and shall pay close attention to the following items:

Roof, ribs, and faces: He shall observe and test roof, ribs, and faces; question each workman as to his ability to detect loose slate or coal; call attention to any slips, faults, kettle-bottoms, or other hazard in the roof; and take immediate steps to make the place safe.

Timbering: He shall see that safety posts are set and the place timbered in the standard manner and that an ample supply of timber is on hand and properly stored; and see that all dangerous or doubtful roof or coal on his section is immediately taken down or safely secured by standard timbering; if this is not practicable he shall fence, in the standard manner, the dangerous place until it can be made safe, see that no person enters such dangerous place except for the purpose of making it safe and examine the timbering frequently to see that it has not become dangerous due to overburden, decay or otherwise.

Blocking: He shall require all cars to be blocked effectively.

Clearance: He shall see that proper clearance is maintained and kept free from obstruction.

Tools: He shall see that the men have and know the use of pick, slate bar, axe, goggles, etc., and that they are in good condition.

Shot holes: He shall see that shot holes are properly placed, do not extend beyond the cut, or do not "grip" into roof or rib.

Shooting: He shall see that the proper amount of explosives and incombustible stemming are used and that a sufficient supply is on hand.

Explosives: He shall see that men do not have an excess supply of explosives and that explosives are placed in standard containers and stored in an approved manner.

Car loading: He shall see that mine cars are properly loaded and "cribbed" in a workmanlike manner to eliminate accidents in transportation and avoid spillage on haulageways; he shall also note the general mechanical condition of cars, and mark those needing repairs.

Workmen: He shall note the general attitude and workmanship of the men, calling special attention to wrong methods or dangerous practices and taking such disciplinary measures as are necessary to correct them.

Haulage: He must see that locomotives are in good mechanical condition and that each is equipped with efficient headlight, gong, rerailers, jack, chain, and fire extinguisher and that brakemen are provided with suitable whistles and use them for signaling; that tracks are in good condition, clean, properly alined, free from water, fish-plated, and well-bonded; that lights are maintained at all switches on main haulageway; that guard rails, frogs, and latches are properly blocked; that proper clearance is made and kept unobstructed; and that legs under crossbars are so placed as not to be readily knocked out by derailed trips.

Ventilation: He shall see that all brattices, doors, overcasts, and checks are properly maintained; that airways are kept free and unobstructed by water, falls, ice, etc., and are driven straight and a uniform area maintained; that all ditches through stoppings are properly trapped; that emergency doors are in workable condition at all main doors; that an adequate supply of air is maintained throughout his section; that the laws and mine safety standards are complied with at all times; and that all doors used for ventilating purposes are kept closed at all times except when actually in use. When doors are to be left open, they shall be so marked by him and nailed or otherwise securely held open.

Mining system: The section foreman shall also become thoroughly familiar with the mining system; he shall see that all places are driven on proper "centers" and specified widths and heights maintained and that safety precautions are strictly followed at all times.

Electricity: The section foreman shall see that all contact hazards are properly guarded and bonds in good condition; that all motor and pump gears are guarded; that telephone lines or signal wires are thoroughly insulated where crossed by power lines; and that trolley wire is guarded wherever less than 6-1/2 feet above the rail and is hung at proper height and alinement. He must instruct all men working near power wires how to protect themselves from contact hazards.

He shall mark all places for cuts and see that projections are followed, all places kept on centers with straight ribs and that tracks are properly placed to secure proper clearance width and depth of cut.

Personal injuries: The section foreman shall see that administration of first aid is properly supervised and the patient

comfortably and promptly removed from the mine when necessary. He shall investigate all injuries received on his section, make an accurate report, and take proper steps to prevent recurrence of similar accidents.

Discipline: He shall enforce on his section all the regulations required by the State mining laws and company rules, and such verbal orders as he may receive from his superior, and shall impose the proper penalties for violations of such regulations.

RULES FOR BOSS DRIVER

1. The boss driver shall have general supervision of all underground men engaged in haulage. He shall report immediately to the mine foreman for disciplinary action all violations by haulagemen of rules and regulations for safe practice.

2. He shall require drivers to be ready to begin work at the stated time and that the animals are properly watered and fed during the day.

3. He shall see that every driver does his work faithfully and does not abuse his animals and that all harness is kept in good repair, reporting needed repairs to the stable boss.

4. He shall require all tracks to be kept clean and in good repair, reporting substandard conditions to the mine foreman.

5. He shall make a prompt, full, and complete report to the mine foreman of any accident to drivers or animals as well as to others, caused by haulage.

6. He shall enforce strictly the rules governing drivers and other haulagemen in relation to the distribution of cars.

7. He shall report daily to the mine foreman all derailments, stating the location, cause, weight of the rail where the derailment occurred, stating whether the derailment caused an accident to any employee and nature of the injury, damage to track and equipment, and the approximate loss in production due to this particular derailment.

8. He shall pick up and properly dispose of all metal or other material of any nature or character that might be dangerous if loaded out in the coal.

RULES FOR STABLE BOSS AND ASSISTANT

1. The stable boss shall have full charge of all stable stock, and any orders issued by him to the drivers must be complied with at once.

2. He shall examine the animals daily as they come from work and report any sick or injured animals to the mine superintendent.

3. He shall have general care of the stock and see that they are fed, watered, and attended in the proper manner. He shall not allow any animal to be ill treated or overworked, or permit any animal not fit for work to leave the stable. If an animal is brought out bearing evidence of ill treatment, he shall make a full report to the mine foreman.

4. A record shall be kept of the amount of hay and grain used each month, and orders for feed must be made early enough to insure that an adequate supply will be on hand at all times.

5. Stablemen shall bear in mind at all times the hazard of fire and shall obey the rules as to fire prevention and keep fire-fighting equipment ready for immediate use.

RULES FOR MASTER MECHANIC AND CHIEF ELECTRICIAN

1. The master mechanic and chief electrician shall have full charge of all machinery and appurtenances in their departments and must retain none but competent, careful, and sober men.

2. They shall see that all machinery in their respective departments is kept in thorough repair.

3. The electrician shall make a systematic inspection of all wiring and equipment at least once each month. A report of each inspection shall be made and a copy furnished the mine foreman to be carefully read by him and kept on file at the mine.

4. Repairs, renewals, or extensions of electrical apparatus and circuits shall be made while such apparatus or circuits are not "alive;" the utmost precaution must be observed when it is necessary to make repairs on "live" apparatus or circuits. While working on apparatus or circuits that have been disconnected from the power supply, precaution must be taken to prevent unauthorized persons from closing switches.

5. In case of damage to machinery through neglect of duty of any employee the offender will be held responsible for such damage.

6. Boilers and steam gages shall be tested at least twice a year and scale or sediment removed from boilers when necessary. Safety valves on boilers shall be operated at least once each week. A record shall be kept of such tests.

7. Parts of idle machinery may be removed in case of emergency, but these parts shall be put on requisition immediately and the idle machine restored promptly to serviceable condition, particularly if it is used in connection with safety.

8. Orders for parts and general supplies shall be made in time to be on hand when needed. It shall be the duty of the master mechanic

and chief electrician to ascertain whether enough necessary material is on hand and to anticipate future requirements.

9. The fan shall not be stopped without the permission of the mine superintendent; if the fan must be stopped for repairs the mine foreman must be given timely notice. The speed of the fan or the direction of air flow shall not be changed under any circumstances without the permission of the mine superintendent and the knowledge of the mine foreman.

10. Fire extinguishers, fire hose, nozzles, rock-dust containers, or any of the connections to them shall not be removed from their places or used for any purpose except in case of fire.

11. The master mechanic and the chief electrician will carefully instruct all new employees in their respective departments in their duties, pointing out the hazards of their work and the proper manner of performing their duties safely.

12. It will be the function of the master mechanic and chief electrician to discipline employees in their respective departments and require their compliance with rules and regulations promulgated for their work and safety.

13. The master mechanic and chief electrician shall see that all gears, belts, or other moving parts of machinery are protected to prevent persons from catching clothes, hands, or bodies in them.

14. It shall be the duty of the master mechanic to see that all slope man-trips and cages where men are hoisted are inspected daily, with written report made of these inspections and kept on file.

15. It shall be the duty of the electrician to see that all electrical appliances are in proper working order; that all wires are properly insulated; and that all cables or insulated wires carrying current of a dangerous voltage have the insulation kept in proper repair; also, that all trolley wires shall be kept properly tightened and protected in such condition that workmen or animals cannot come in contact with them because of loose fastenings or sagging from any cause.

16. The mine electrician shall maintain an electrical plan map showing the location of all permanently installed electrical machinery and apparatus in connection with the mine electrical system, including cables, conductors, motors, switches, trolley lines, and transformers; the plan shall be corrected as often as necessary to keep it up-to-date at intervals not exceeding 6 months.

17. Prohibitory notices shall be posted conspicuously to prevent manipulation of electric apparatus by unauthorized persons.

18. Instructions for the resuscitation of persons suffering from electric shock shall be posted prominently at every surface and underground station or mine entrance.

19. Electric power shall not be permitted on any line, in any mine, or in any section of the mine after working hours. Machine runners, helpers, motormen, drillers, and others whose duties require them to use power shall cut the power off at switches installed for that purpose, in sections or parts of sections, at the end of each shift.

RULES FOR PUMPMEN

1. It shall be the duty of the pumpmen to keep the pumps in their charge in good condition for service and to see that they perform the work required of them.

2. They shall maintain neat and orderly pumprooms, keeping both clean and oily waste in receptacles provided for that purpose.

3. Reports of insufficient power or low voltage must be made daily until remedied.

4. When pumps are operated constantly each shift shall remain at its post until relieved.

5. Ordinary repairs of pumps and pipes shall be made by the pumpmen.

6. Serious damage or breakage of pumps, or failure to keep the water within safe limits, shall be reported immediately to the master mechanic or mine foreman.

7. Precautions shall be taken against the loss of a pump through roof fall or drowning.

8. All machinery shall be stopped before attempting to oil or grease it.

9. Couches or improvised beds in pumprooms are prohibited.

RULES FOR REPAIRMEN AND WIREMEN

1. Repairmen and wiremen shall not wear loose clothing; trouser legs must be worn inside of high shoes, leggings, or sock legs, and jumpers inside of overalls. These employees shall wear rubber shoes and short gloves.

2. Repairs shall not be made to any piece of equipment while it is in operation, but only after the workmen are certain that the power has been disconnected and have assured themselves that it cannot be turned on accidentally.

3. Repairmen or wiremen shall not work on "hot" lines of any kind without wearing tested rubber gloves.

4. Repairmen or wiremen shall not make extensions to trolley lines until the cut-off switch has been opened and a sign attached cautioning persons against closing it; the trolley wire should be grounded to the rail as an additional precaution.

5. Repairmen, after making repairs or inspections of any piece of equipment, shall be held responsible for the replacement of all bolts, nuts, studs, and guards and give special attention to the correct assembling of all equipment, particularly permissible equipment.

6. All compartments on Government-approved machines must be absolutely tight, with all bolts in place and all seals and vents in proper condition, to comply with the provisions of the approval plates.

7. Repairmen shall be held responsible for the wiring, insulation, and grounding of all equipment installed by them.

8. Repairmen or wiremen who make extensions to trolley circuits shall, on completion of their work, have all crossings guarded and bondings extended to the end of wire and also have wire dead-ended with proper insulators.

9. Repairmen and wiremen shall replace all broken guard boards and bonds reported to them.

10. Repairmen and wiremen will be held responsible for tools required for their work and they shall be returned in good condition.

RULES FOR TIMBERMEN AND SLATEMEN

1. The duties of men performing this class of work often make it necessary to deal with dangerous conditions, and they are therefore required to take special care to avoid injury to themselves and others.

2. They shall examine conditions at places where they are directed to work, and approach dangerous conditions by making everything safe about them and above them as they advance.

3. They shall not take unnecessary risks and, if sufficient and suitable timber or other material is not at hand to make the conditions safe as they proceed, they shall cease work and notify the mine foreman or his assistant and shall not resume work at that place until such timbers and materials are furnished.

RULES FOR TRACK LAYERS

1. Any persons engaged in the occupation of trackman or assistant in the mine shall exercise due care and economy in the use of material and supplies. When working on tracks and haulageways traversed by mules or locomotives hauling cars they shall give proper notice that the track is

[illegible] required, so that all movements of trips will approach that place slowly. Before beginning work on a track they shall examine the condition of the mine at the place where the work is to be performed and take whatever precautions are necessary to insure their safety.

RULES FOR TRAPPERS

1. Trappers shall carry out at all times the duties imposed upon them by the mine foreman and, unless the job requires it, they shall not ride on or tamper in any manner with passing cars, motors, machines, or live stock.

2. Doors must be opened by them in time for the passage of drivers or motor trips and then properly closed, and they must also see that switches are thrown properly. They shall take a safe position while trips are passing through.

CONCLUSION

The Bituminous Coal Code contains a general provision covering safety, as follows: "Employers and employees shall cooperate in maintaining safe conditions of operation in compliance with the applicable requirements of State laws or regulations in conformity therewith." Supplementary State and district agreements between the miners' union and the operating companies contain a safety clause as follows: "Reasonable rules and regulations of the operator for the protection of the workers and the preservation of property shall be complied with." Neither of these is sufficiently specific to be of practical value in actually providing means or methods or devices for the avoidance of accidents; in general, State laws are anything but up-to-date or adequate as to safety in mining, hence every mine owes it to itself as well as to its employees and the community to have its own specific and adequate rules definitely set out in printed or multigraphed form.

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Department of the Interior

United States Bureau of Mines
John W. Finch, Director

INFORMATION CIRCULAR

TUNGSTEN - PART I

BY

William O. Vanderburg

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INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

TUNGSTEN - PART I [1]

By William O. Vanderburg[2]

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1/ The Bureau of Mines will welcome reprinting of this article providing the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6821."

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INTRODUCTION

This circular is one of two papers on the tungsten industry in the United States and contains general information on the subject. The second paper which will be issued in the near future deals with the methods and costs of mining and milling tungsten ores. These two papers are abstracts from the general bulletin on tungsten which will be issued at some future time.

Modern civilization and progress depend largely on tools wherewith the forces of nature are brought under control and directed toward human comfort. These tools are made chiefly from metals derived from the earth's crust. During the present century powerful tools have been made available through the development of ferrous and nonferrous alloys containing such elements as molybdenum, vanadium, titanium, tantalum, and tungsten, which were little used before 1900. One of the most important of these so-called rare elements is tungsten; its use in alloys for high-speed cutting tools is partly responsible for the era of mass production. So widespread has the use of alloys become that the period may be termed an "Alloy Age".

Tungsten is recognized as an essential ingredient of the best high-speed cutting tools. The major part of the 4,300 tons of tungsten concentrate containing 60 percent tungsten trioxide (WO_3), consumed annually in the United States under normal conditions, is used in the manufacture of such tools.

HISTORY

In 1747, Wallerius selected the name tenn-spat (heavy spar or heavy mineral) for a new mineral species from Bohemia believed to contain tin.3/ In 1781, K. W. Scheele, the celebrated Swedish chemist, examined a specimen of Wallerius tenn-spat (Swedish, tung-sten) and demonstrated that the mineral contained a peculiar acid united to lime as a base. This acid he called tungstic acid. In the same year T. Bergman stated that this acid was an oxide of a new element, tungsten. From 1783 to 1786 the d'Elhuyar brothers, Juan, Jose, and Fausto, Spanish chemists, showed that the same acid discovered by Scheele is contained in the mineral wolframite. They also succeeded in producing metallic tungsten from the acid.4/ The term "wolframite" was applied to tungsten minerals long before their nature was understood.

In 1801, a short note in Nicholson's journal states that Guyton had melted tungsten; but it was brittle and probably of use only in alloys, for making fixed colors, or for fixing vegetable colors - three of its present uses.5/

3/ Levy, S. I., The Rare Earths: Edward Arnold, London, 1915, p. 31.
4/ Roscoe, H. E., and Schorlemmer, C. A., A Treatise on Chemistry: Vol. 2, 1913, pp. 1082-1083.
5/ Thorpe, Sir Edward, A Dictionary of Applied Chemistry: Vol. 5, 1913, p. 563.

As early as 1855,[6] Jacobs and Koeller of Austria used tungsten as a constituent of alloy steel. They obtained patents in France for its production.

Patents were issued to Oxland in England in 1847[7] for the manufacture of sodium tungstate, tungstic acid, and metallic tungsten from wolfram-tin ores. These were followed by a patent issued in 1857 for the production of certain alloys with iron and steel, nickel, and other elements.

Probably the first useful alloy steel containing tungsten was Mushet's self-hardening tungsten tool steel, patented in 1868. This steel, now obsolete, contained about 6 percent tungsten and 2 percent manganese. In regard to the use of tungsten for hardening steel, the old Damascus steel, long celebrated for its retention of temper, has been found to contain both tungsten and chromium,[8] although not intentionally added.

The real birthdate of the tungsten tool-steel industry was 1898, when F. W. Taylor, in collaboration with Maunsel White, discovered a steel that could be used to cut at high speed. Taylor-White steels manufactured at the works of the Bethlehem Steel Co. were exhibited at the Paris Exposition in 1900 and created a great sensation among those interested in working metals. These tools could be used above temperatures that would ruin any carbon steel. White stated[9] that a young man in the Bethlehem shop in 1900 lighted a cigarette with a chip newly cut with Taylor-White steel, a statement almost unbelievable at that time.

In 1903 Hadfield published the results of his studies of the properties of tungsten steels. These extensive investigations contributed largely to the demand for tungsten tool steels.

In addition to cutting at higher speeds, tungsten-steel tools were found to be capable of taking heavier cuts, which increased the stresses on the machines. To take full advantage of the heavier as well as the more rapid cuts machines were redesigned to provide the greater strength required. The resulting economies effected all over the world were enormous, and the new tungsten-steel tools were the dominant factor in the new era of mass production of machine-tool products.

The extremely high melting point of tungsten suggested its use for electric-lamp filaments, but at the time of its introduction as a lamp filament (1904) it was known only as a powdery, hard, brittle metal which it was impossible to render coherent and ductile. Numerous processes were invented and patented wherein the filaments were made with powdered tungsten; these were used with more or less success until drawn tungsten wire for

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6/ Gurlt, Adolph, On a Remarkable Deposit of Wolfram Ore in the United States: Trans. Am. Inst. Min. Eng., vol. 22, 1893, p. 236.
7/ Roscoe, H. E. and Schorlemmer, C. A., work cited.
8/ Thorpe, Sir Edward, work cited.
9/ Hibbard, Henry D., Manufacture and Uses of Alloy Steels: Bull. 100, Bureau of Mines, 1916, p. 54.

incandescent lamp filaments was developed by the General Electric Co. The ductile tungsten-lamp filament was introduced in 1907. The greater efficiency of the tungsten electric lamp over the types of lamps formerly used resulted in the saving of millions of dollars annually.

Within the last few years a new tungsten compound has been developed which bids fair to supersede the former high-speed tool steels in cutting efficiency. This new material is known as cemented tungsten carbide; cobalt is used as the cementing agent. The material was first developed in Germany; Baumhauer and Schröter are given the major credit for its development. The patents are held by Fried. Krupp Aktiengesellschaft, Essen, Germany; in this country licensees manufacture it under the trade names carboloy, firthite, firthalloy, dimondite. Tungsten carbide is the hardest artificial substance known, exceeding the sapphire and approaching the diamond in hardness. Properly made, tungsten-carbide tools will cut chilled castings, manganese steel, porcelain, mycalex (fine mica in lead borate), ivory, quartz, and other substances not readily cut with other tools.

Few elements have shown greater development in so short a time as tungsten. Before the present century tungsten was more of a scientific curiosity than a metal of commercial importance, but with introduction of Taylor-White tool steel it was lifted out of the category of rare metals to a position where it has become one of the key metals of our present economic structure.

TUNGSTEN MINERALS

Tungsten is never found in nature in the metallic state. It is an acid-forming element and therefore does not act as a true metal in its compounds. The economic tungsten minerals are tungstates, in which the tungsten is combined with oxides of calcium, iron, and manganese. Although a number of tungstic acids have been prepared artificially salts of only one acid have been found in nature, namely, those of the normal tungstic acid (H_2WO_4). Tungsten has been identified in a number of minerals as impurities, but only 12 distinct species of minerals containing tungsten are known. In virtually all of its minerals tungsten is one of the chief constituents, the two exceptions being powellite and chillagite.

Table 1 lists the known tungsten minerals and gives their theoretical composition and the percentage of tungsten each mineral contains:

TABLE 1. - Tungsten minerals

Mineral	Composition	Tungsten, percent[1/]
Scheelite	Calcium tungstate ($CaWO_4$)	63.9
Ferberite	Iron tungstate ($FeWO_4$)	60.6
Wolframite	Iron-manganese tungstate ($(Fe,Mn) WO_4$)	60.6-60.7
Hübnerite	Manganese tungstate ($MnWO_4$)	60.7
Powellite	Calcium-tungstomolybdate ($Ca (MoW) O_4$)	-
Chillagite	Lead tungstate-lead molybdate ($3PbWO_4.5PbMO_4$)	17.2
Stolzite	Lead tungstate ($PbWO_4$)	40.4
Raspite	Lead tungstate ($PbWO_4$)	40.4
Cuprotungstite	Hydrous copper tungstate ($CuWO_4.2H_2O$)	52.9
Tungstite	Hydrous tungsten trioxide ($WO_3.H_2O$)	73.6
Tungstenite	Tungsten sulphide (WS_2)	74.6
Ferritungstite	Hydrous iron-tungsten oxide ($Fe_2O_3.WO_3.6H_2O$)	41.5

1/ Based on theoretical composition.

Stolzite and raspite differ only in crystal form, the former being tetragonal and the latter monoclinic.

Reinite ($FeWO_4$) as given by Dana[10/] is a separate species, but it is now regarded as ferberite pseudomorphous after scheelite.

Cuproscheelite, according to Dana, is a tungstate of copper and calcium $(Ca,Cu)WO_4$; it may be scheelite partly altered to cuprotungstite in which the calcium has not been wholly replaced by copper.

Meymacite, named by Carnot, is probably the same as tungstite.

The term "megabasite" has been used in early reference on tungsten as a synonym of hübnerite.

Of the above list only the first four minerals - scheelite, ferberite, wolframite, and hübnerite - are found in large enough quantities to be economically important as ores of tungsten. The others are to be considered in the light of interesting mineralogical occurrences. Besides these Dana's System of Mineralogy mentions that small amounts of tungsten are contained in the tantalum-columbium minerals, but the information concerning them is so incomplete that their existence as definite mineral species can not be considered authentic.

10/ Dana, J. D., and Dana, E. S., A System of Mineralogy: New York, 6th ed., 1911, p. 991

CHARACTERISTICS OF ECONOMIC TUNGSTEN MINERALS

The physical and chemical properties of the four principal tungsten minerals are given in table 2.

TABLE 2. - Physical and chemical properties of economic tungsten minerals

Mineral	Ferberite	Wolframite	Hübnerite	Scheelite
Composition (pure)	$FeWO_4$	$(Fe,Mn)WO_4$	$MnWO_4$	$CaWO_4$
Per cent WO_3 and W	76.3; 60.6	76.5; 51.3	76.6; 60.7	80.6; 63.9
Crystallization	Monoclinic.	Monoclinic.	Monoclinic.	Tetragonal.
Cleavage	Perfect in 1 direction.	Perfect in 1 direction.	Perfect in 1 direction.	Good in 4 directions.
Specific gravity	7.5	7.1-7.5	7.2-7.3	5.4-6.1
Color	Black	Dark gray to black.	Reddish brown to black.	Pale yellow, brown, commonly white.
Tenacity	Very brittle.	Very brittle.	Very brittle.	Very brittle.
Luster	Submetallic to metallic.	Submetallic to metallic.	Submetallic to adamantine.	Vitreous to resinous.
Fracture	Uneven.	Uneven.	Uneven.	Uneven.
Hardness	5	5-5.5	5	4.5-5
Magnetism	Sometimes feebly magnetic.	Slightly magnetic.	-	Nonmagnetic.
Streak	Dark brown to nearly black.	Dark brown to black.	Brownish red to greenish yellow.	White
Diaphaneity	Opaque to weakly translucent in cleavage plates.	Opaque.	Opaque to translucent.	Transparent to translucent.
Common form of occurrence	Well-defined crystals, massive cryptocrystalline.	Irregular masses.	Radiating groups of thin-bladed crystals.	Massive and small grains.

The three minerals ferberite, wolframite, and hübnerite form a continuous series of iron-manganese tungstates, of which ferberite is the member at the iron end and hübnerite is the member at the manganese end. The iron and manganese contents of the wolframite series are so variable that the minerals cannot be distinguished without chemical analyses. No specimen of ferberite free from manganese or hübnerite free from iron has been found in nature. Since the wolframites form a complete series with an indefinite number of

members any classification of the minerals into ferberite, wolframite, and hubnerite must necessarily be arbitrary. The following definitions proposed by Hess[11] are generally accepted:

Ferberite. A monoclinic iron tungstate having when pure the composition $FeWO_4$. It may contain not more than 20 percent of the hubnerite molecule $MnWO_4$.

Wolframite. A monoclinic mineral containing the ferberite molecule ($FeWO_4$) and the hübnerite molecule ($MnWO_4$) in all proportions between 20 percent $FeWO_4$ and 80 percent $MnWO_4$ and 80 percent $FeWO_4$ and 20 percent $MnWO_4$.

Hübnerite. A moloclinic manganese tungstate having when pure the composition $MnWO_4$. It may contain not more than 20 percent of the ferberite molecule $FeWO_4$.

The wolframites are metallic in appearance, while scheelite looks like stone.

The economic tungsten minerals are characterized by high specific gravity,[12] ranging from 5.4 (scheelite) to 7.5 (wolframite). (See table 2.) The tungsten minerals are 2 to nearly 3 times as heavy as quartz, which has a specific gravity of 2.6. This property of the tungsten minerals is utilized in making a separation between quartz, calcite, and other minerals of lower specific gravity when ores are concentrated by gravity methods.

Because of their similarity in chemical composition and the fact that the atomic weights of iron and manganese are almost the same (Fe, 55.84; Mn, 54.93), the wolframites contain almost the same percentages of tungsten trioxide.

Each of the wolframite series of minerals has a perfect plane of parting (cleavage) in one direction. Scheelite has eight planes of parting, four of which are pronounced and four which are not pronounced.

The principal tungsten minerals have a hardness of about 5, as measured on the Mohs scale of hardness;[13] they are easily scratched with the blade of a good pocket knife, which has a hardness of about 5 1/2.

The streak of a mineral (the color of its fine powder) usually is obtained by rubbing the mineral on a piece of unglazed porcelain and brushing off the excess, or it may be obtained less satisfactorily by pulverizing a

11/ Hess, Frank L., and Schaller, Waldemar T., Colorado Ferberite and the Wolframite Series: U. S. Geol. Survey Bull. 583, 1914, pp. 37-38.

12/ The specific gravity of a substance is its weight compared with that of an equal bulk of water at the temperature of greatest density (4°C. or 39.29° F.).

13/ Mohs' scale of hardness, which is used for minerals, is: 1, Talc; 2, gypsum; 3, calcite; 4, fluorite; 5, apatite; 6, feldspar; 7, quartz; 8, topaz; 9, sapphire; 10, diamond.

fragment of the mineral or by scratching the mineral with a knife or file. The streak of the wolframites ranges from black in wolframite through brown to brownish red in hübnerite. The streak of scheelite is white.

OCCURRENCE

Tungsten is rated as the thirty-eighth[14] element in the order of abundance in the earth's crust; it is less abundant than tin or silver, the thirty-third and thirty-seventh elements, respectively, but is more abundant than gold, the forty-first element. Tungsten is distributed very unequally over the earth as a whole; it is distributed more widely than tin, with which it is commonly associated, but less widely than gold. The chief tungsten-producing districts of the world follow the volcanic chain which skirts the Pacific Ocean. Although the deposits are not always near the shore they are somewhere in the mountain ranges that parallel it. From 1905 until 1930, 88.4 percent of the total world production of tungsten concentrates came from countries bordering the shores of the Pacific. Of this percentage the west coasts of North and South America produced 25.2 percent and the east coast of Asia and Oceania (Australia and New Zealand) 63.2 percent. The only large producing area not close to the Pacific is that of the Iberian Peninsula, including Portugal and part of Spain. Of the 11.6 percent of the world production of tungsten concentrates from countries not bordering the Pacific, the Iberian district produced 7.8 percent.

Tungsten deposits are represented in almost every type of ore deposit; these include placers, veins, contact-metamorphic deposits, replacement deposits, pagmatites, and segregation deposits. Viewed in the light of past production placers have been the most important source of tungsten minerals.

Tungsten deposits, like tin and molybdenum deposits, are virtually always associated with siliceous igneous rocks, especially granites or acid pegmatites; in this respect they differ from any other minerals. The converse of this statement is not true, however, as large areas of granitic rocks all over the world are not associated with tungsten deposits. Most of the tungsten deposits in place lie wholly within or at the margins of the acid igneous rocks; some, however, lie within sedimentary rocks, such as slates and shales, or metamorphic rocks, such as schists. Where the tungsten deposits lie within the latter rocks and siliceous rocks are not in evidence in the immediate vicinity the underlying granitic rock is not far distant.

PRODUCTION AND CONSUMPTION

The United States is one of the largest consumers of tungsten. Although it also ranks as one of the largest producers it has had to supplement domestic supply by importation, principally from China. Before 1900 tungsten ores were derived chiefly from mines in England. Austria, Hungary, Germany, and Australia. The United States became a factor in tungsten production about 1900.

14/ Washington, H. S., Jour. Franklin Inst., vol. 190, 1920, p. 77.

TABLE 3. - World production of tungsten ore, 1905-32, in metric tons of concentrates containing 60 percent WO_3 1/

Country	1905-25	1926	1927	1928	1929	1930	1931	1932
Asia:								
Japan	5,044	19	49	54	61	81	(2)	(2)
Chosen (Korea)	2,857	-	5	161	15	13	(2)	(2)
China	40,656	7,989	5,666	8,283	9,978	9,454	7,492	2,249
Tonkin (Indo-China)	3,466	92	213	175	198	220	248	(2)
Burma and Shan States	32,392	1,634	1,277	843	1,489	2,699	2,474	(2)
Siam	3,441	10	8	-	62	7	12	(2)
Unfederated Malay States	4,557	234	170	139	157	178	241	(2)
Federated Malay States	4,659	99	22	5	356	1,054	462	378
Netherland East Indies	598	9	22	8	10	15	1	(2)
India (excluding Burma)	186	-	-	-	-	-	-	-
Oceania:								
Australia 3/	18,879	99	179	238	223	224	-	-
New Zealand	2,711	15	15	6	39	21	6	(2)
South America:								
Argentina	8,657	11	10	24	63	98	20	(2)
Bolivia	17,798	109	79	29	1,630	888	410	1,000
Peru	2,673	-	-	-	-	-	-	-
North America:								
Canada	116	-	-	-	-	-	-	-
Mexico	1,068	-	-	-	11	28	(2)	(2)
United States	31,279	1,254	1,056	1,096	753	637	1,274	359
Europe:								
Sweden	38	-	-	-	-	-	-	-
England	4,239	20	12	96	27	153	121	(2)
France	1,688	26	22	5	1	-	-	(2)
Portugal	15,476	358	174	151	358	499	274	(2)
Spain	4,116	123	164	193	257	254	135	(2)
Italy	88	-	-	-	-	-	-	-
Austria	574	-	-	-	-	-	-	-
Germany	2,034	-	-	-	1	-	-	(2)
Czechoslavakia	335	86	78	73	75	74	17	(2)
Russia	199	22	32	58	(2)	(2)	(2)	(2)
Africa:								
Southern Rhodesia	192	-	33	15	28	38	24	14
Union of South Africa	322	-	-	-	-	-	2	-
Nigeria	32	-	-	-	-	-	-	-
All other Countries	43	-	-	(4)	-	-	-	-

1/ Data from the U. S. Geological Survey and U. S. Bureau of Mines.
2/ Data not available.
3/ Includes Tasmania.
4/ Ethiopia reports an experimental production of 100 tons of tungsten ore in 1928; WO_3 content not stated.

From 1905 to 1931 the total world production has been about 279,400 metric tons of concentrates containing the equivalent of 60 percent WO_3. Out of this production China produced approximately 32 percent, Burma and Shan States 14.5 percent, United States 13.5 percent, Bolivia and Australia each 7 percent, and Portugal 6 percent. Table 3 shows the world production of tungsten from 1905 to 1932.[15/]

Figure 1 shows the world production, United States production and apparent consumption of tungsten from 1905 to 1932. In the figure figures on consumption and production are reduced to equivalent short tons of concentrates containing 60 percent WO_3.

The international balance sheet of tungsten covering data from 1925 to 1926 is estimated to be approximately as shown in table 4.[16/]

TABLE 4. - International balance sheet of tungsten

Supply			Demand		
	Metric tons	Percent of total		Metric tons	Percent of total
China	8,020	63.4	United States	3,900	30.8
Burma	1,610	12.7	Germany	3,850	30.5
United States	980	7.8	United Kingdom	1,700	13.4
Bolivia	470	3.7	France	3,000	23.7
Unfederated Malay States	170	1.3	Japan	200	1.6
Portugal	230	1.8			
Australia	200	1.6	Total	12,650	100.0
Tonkin	190	1.5			
Spain	140	1.1			
Federated Malay States	260	2.1			
All others	380	3.0			
	12,650	100.0			

15/ Data from annual Mineral Resources of the United States Geological Survey 1906-23) and the United States Bureau of Mines (1924-31) and from the Minerals Yearbook of the Bureau of Mines (1932).

16/ Hess, Frank L., Tungsten: Mineral Resources of United States, Bureau of Mines, 1930, part I, 1932, pp. 179-207.

TUNGSTEN DEPOSITS IN THE UNITED STATES

The known tungsten deposits in the United States lie mainly in the area between the Rocky and Sierra Nevada Mountains. Thirteen States have at some time in the past produced tungsten concentrates; in the approximate order of their importance as producers they are: Colorado, California, Nevada, Arizona, South Dakota, Washington, Montana, New Mexico, Utah, Idaho, Connecticut, Missouri, and Oregon. The bulk of the production has been derived largely from the first three States. In addition to the above States tungsten minerals have been reported from several others, but these occurrences are of mineralogical rather than actual or potential economic importance.

Arizona.- Virtually all of the tungsten deposits of Arizona are vein deposits, several of which are associated with placers. Fifteen widely scattered deposits occur in various parts of the State; most of these have been worked at some time during the past 15 years, but production from the individual deposits has been small and rather sporadic. In recent years the two most important properties in the State have been the Boriana Mines Co., which operates a consolidation of properties about 16 miles northeast of Yucca, and the Tungsten Alloys Corporation, which owns property in the Las Guigas Mountains 65 miles south of Tucson.

California.- The most important deposits in California are in San Bernardino, Inyo, and Kern Counties. Five other counties in the State contain tungsten deposits. The chief producing area has been the Atolia district, with an output of tungsten concentrates valued at $12,000,000. In this district the ore mineral is scheelite, which occurs in veins and placers. Important contact-metamorphic deposits were developed near Bishop and at Pine Creek, Inyo County. Several properties built large mills between 1916 and 1918, but as the demand and price of tungsten concentrates dropped considerably at the close of the war the plants were forced to close down. The ores of the Bishop and Pine Creek districts are of low grade. Other districts in the State have produced small amounts of tungsten concentrates; but because of adverse conditions, such as lack of cheap transportation, long distance from power, and scarcity of water and timber in the immediate vicinity of the deposits, many have not been prospected or developed thoroughly.

Colorado.- The production of tungsten concentrates in Colorado has been derived almost entirely from the ferberite vein and placer deposits of the Boulder field, which is about 12 miles long and several miles wide. This field contains the largest deposits of ferberite in the world; these were worked intensively during the war period. At that time there were 21 concentrators in the district. In recent years the Wolf Tongue Mining Co. has been the largest and most consistent producer in the district.

The tungsten deposits in other parts of the State have not been important producers.

Connecticut.- A small deposit of scheelite and wolframite ore has been worked at Long Hill 8 miles south of Trumbull, Conn. The mill at this property burned in 1916, and no production has been made since.

Idaho.- Tungsten deposits have been found in six widely scattered districts in Idaho. The deposits that have been worked are in Shoshone County, adjoining the gold camp of Murray, and in the Patterson Creek district, Lemhi County. In the Murray district the Golden Chest and Golden Winnie Mines have produced small amounts of scheelite, which occurs with gold. In the Patterson or Blue Wing district the Ima Mine has produced a small amount of hübnerite, which is associated with tetrahedrite and copper. In recent years the production from the tungsten properties in the State has been negligible.

Missouri.- The Old Einstein mine in the granitic area of Madison County 12 miles west of Fredericktown has produced small quantities of hübnerite. This property was first opened in 1877 for argentiferous galena with which the hübnerite is associated.

Montana.- The Jardine Mining Co. at Jardine, Mont., has made intermittent shipments of scheelite concentrates within the last few years. Here the scheelite is associated with gold and arsenopyrite in quartz veins. Both the gold and arsenopyrite are more important economically than the scheelite. Several other deposits of tungsten ores occur within the State but thus far have been only small producers.

Nevada.- Most of the tungsten concentrates produced in the United States with the last 5 years have been derived from the contact-metamorphic deposits in the Eugene Mountains 7 miles northwest of Mill City, Pershing County, Nev. These deposits are owned by the Nevada Massachusetts Co., Inc. The Silver Dyke mine in the Silver Star district, Mineral County, has also been a major producer of scheelite concentrates; it is also owned by the Nevada Massachusetts Co., Inc. A new mill was erected on this property in 1930. Another potential producer of scheelite in Nevada is the Tungsten Production Co. in the Nightingale district, Pershing County. A concentrator was built on this property in 1930 to treat the scheelite ore, which occurs in contact-metamorphic deposits.

In the past a considerable production of tungsten concentrates has been made from the vein and placer deposits in the Snake Range in the eastern part of the State. Since the World War, however, Snake Range deposits have been inactive.

The tungsten vein deposits scattered throughout the State have been worked intermittently on a small scale. Probably not more than 25 percent of the contact-metamorphic deposits have been prospected or developed to any extent because of scarcity of water and timber in the vicinity of the properties, long distance from hydroelectric power lines, and recent discovery. Virtually all the contact-metamorphic tungsten deposits of Nevada and California were discovered between 1916 and 1918. These deposits constitute the largest reserve of tungsten ores in the United States.

New Mexico.- Tungsten ores have been found in four districts of the State. The small quantities of tungsten concentrates produced were mainly byproducts from the mining of gold, silver, and copper ores.

Oregon.- During the World War a small quantity of concentrates was produced from the gold-scheelite veins in the Cliff mine, Virtue district. There is no record of any production of tungsten from Oregon in recent years.

South Dakota.- South Dakota has produced tungsten concentrates valued at $1,300,000, largely from the replacement deposits in the Lead-Deadwood area. The principal mines in this area have been the Wasp No. 2 and the Homestake. Production from this State since 1928 has been negligible. The pegmatites of the Harney Peak and Tinton districts have yielded small quantities of tungsten concentrates.

Utah.- Two deposits of tungsten ores of economic importance occur in Utah, one in the Grouse Creek Mountains and the other in the Clifton district, Tooele County. Neither has been a large producer.

Washington.- Seven tungsten deposits occur in Washington, four of which are in Stevens County. The most important tungsten property in the State has been the old Germania mine, now owned by the Tungsten Producers, Inc., in the Deer Trail district; the economic tungsten minerals are wolframite and scheelite, which occur in quartz veins. A new mill was erected on this property in 1931. The Tungsten Mines, Inc., and the Northwest Tungsten Co., Inc., have been developing their properties within the last 3 years.

TECHNOLOGY OF TUNGSTEN ORES

The mining of tungsten ores in the United States involves no factors which are not inherent in mining similar types of ore deposits of the other metals. In mining narrow deposits of tungsten ores where the enclosing rocks are structurally strong, the open-stope or shrinkage-stope methods of mining are employed; where the wall rocks are weak the cut-and-fill system is used. In mining disseminated ores where the deposits occur in large, irregular masses, the glory-hole system of mining has been employed, as at the Pine Creek and Round Valley mines near Bishop, Inyo County, Calif.

Placer tungsten deposits in the United States generally are worked on a small scale by hand methods; the one exception is the placer deposit at Atolia, San Bernardino County, California, which has been worked by power shovel.

At present the concentration of tungsten ores in the United States depends basically on wet gravity methods, although recent research work by the Bureau of Mines[17] has demonstrated that some tungsten ores are amenable to the flotation process.

In deposits where the tungsten mineral occurs in coarse form the ore is crushed and then concentrated by jigs followed by further crushing and the use of tables for recovering the finer particles. When the tungsten mineral occurs in fine particles, stage-crushing by rolls is followed by classification before

17/ Coghill, Will H. and Clemmer, J. Bruce, Soap Flotation of the Nonsulphides: Am. Inst. Min. and Met. Eng., Tech. Pub. 445, 1932, pp. 13-16.

table treatment. If pyrite, garnet, epidote, or chalcopyrite is present in the bulk table concentrate magnetic separators are used to remove these minerals to produce a cleaner product.

In concentrating tungsten ores by gravity methods the main object is to remove the tungsten mineral in as coarse a form as possible to avoid excessive loss of the mineral in the slimes. The economic tungsten minerals are brittle and slime readily, therefore rolls generally are employed for secondary crushing in stages, in preference to stamp or ball mills.

CONVERSION OF CONCENTRATES

Steel Making

In the manufacture of tungsten steel the concentrates may be introduced directly into the steel bath; because of the greater purity of the concentrates this method is increasing in use. As the calcium in scheelite slags more readily than manganese in wolframite, scheelite is the more suitable tungsten mineral for this purpose.

Tungsten is also introduced into steel in the form of ferrotungsten; in addition, tungsten powder has been employed in steel making, but its use in the United States has almost ceased.

Production of Ferrotungsten

Ferrotungsten is produced directly from clean concentrates containing at lease 60 percent tungsten trioxide, from tungsten trioxide, or from tungsten powder. In general three methods are employed in the manufacture of ferrotungsten:

1. Electric furnace reduction with or without carbon.
2. Aluminothermic reduction.
3. Crucible reduction with carbon.

The first method is perhaps that used most generally in the United States. Economical production of high-grade ferrotungsten from scheelite, wolframite, and ferberite involves many problems; copper, arsenic, tin, lead, antimony, bismuth, manganese, and sulphur are troublesome; furthermore, specifications for carbon and silicon in the ferrotungsten must be observed.[18] Preparation of reasonably pure tungsten oxide by wet methods and the electric-furnace reduction of this oxide are steps through which a very high-grade product may be obtained, but such procedure can hardly be classed as economical at the present time in this country.

The electric-furnace method for the production of ferrotungsten at Boulder, Colo., has been described by Keeney.[19] By this method ferberite or other

18/ Becket, Frederick M., The Development of Ferro-Alloys of Tungsten and Vanadium: Chem. and Met. Eng., vol. 30, 1924, p. 391.

19/ Keeney, R. M., The Manufacture of Ferro-Alloys in Colorado: Eng. and Min. Jour., vol. 106, 1918, p. 405.

tungsten concentrate is reduced with carbon in the form of coke; lime and fluorspar also are added. The crude metal obtained is subsequently refined and decarburized.

Before the electric furnace was introduced in industry (about 1900) ferrotungsten was produced mainly by reducing concentrates or tungstic acid with carbon in crucibles. By this process a charge of concentrates, flux, steel or scrap iron, and coke or charcoal was placed in a clay-lined crucible and heated in a gas-fired furnace.

Ferrotungsten can also be made by reducing tungsten concentrates or tungstic oxide with aluminum in the electric furnace. The oxygen contained in the metals present furnish the oxygen for burning the aluminum. The charge is mixed in a magnesia crucible and ignited by a fuse of sodium or barium peroxide and aluminum powder. The ferrotungsten produced is almost free from carbon but may contain aluminum unless there is a slight excess of ore or tungsten oxide. It will also contain any other reducible metals present in the ore.

Production of Tungsten Trioxide

Several methods for the decomposition of tungsten concentrates into tungstic acid have been suggested or patented; in a general way they may be grouped as follows:

1. Fusion with alkaline carbonates.
2. Digestion with caustic alkalies.
3. Digestion with acids.
4. Fusion with sodium sulphate and coke or similar mixtures.

The first two methods are the most important commercially in the United States.

Pure tungsten cannot be produced by direct smelting from its ores or concentrates, as can the more common metals. Metallic tungsten is produced by a two-stage process involving chemical preparation of tungsten trioxide and subsequent reduction in furnaces. A fairly pure tungsten metal in powdered form results. The high melting point of tungsten, more than any other factor, has forced the industry to use these unique methods.

The fusion method of making tungsten trioxide, as used by the Fansteel Products Co., has been described by Jones.[20]

The wolframite concentrates are first pulverized and then mixed with Na_2CO_3, using 15 percent more of the latter than the weight of the WO_3 present. This mixture is ground to minus 100-mesh; and a 300-pound charge is fed into a hand-rabbled gas-fired reverberatory furnace, where it is sintered at 800° C. for 2 hours. After sintering the charge is crushed to pea size, and the sodium tungstate is dissolved in water in wooden tanks equipped with wooden

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20/ Jones, Chester H., Manufacture of Pure Tungsten Metal: Chem. and Met. Eng., vol. 22, 1920, pp. 9-16.

stirring paddles. The solution is then filtered, washed and heated to the boiling point in a wooden or stoneware tank by a steam jet, and an excess of $CaCl_2$ solution is added. The charge is transferred to a stoneware vessel, and about 20 gallons of HCl are added to the heated solution. The supernatant liquor is decanted, treated with lime, and reused in the reaction with sodium tungstate. The precipitate is commercial tungstic acid containing 99.53 percent H_2WO_4. This acid is transferred to enamel-steel tanks and purified further by adding about 5 gallons of NH_4OH and enough distilled water to give a 7-percent solution of ammonium paratungstate. It is heated with steam and filtered through a special wooden press with a paper-filtering medium and glass spigots. The paratungstate solution is evaporated to a small bulk in enameled kettles, and the ammonium fumes are condensed for reuse. The solution is then filtered on stoneware suction filters and the white ammonium paratungstate washed with distilled water. The paratungstate is next treated with a 40-percent solution of C.P. nitric acid in steam-jacketed enamel-lined kettles, where it is converted into H_2WO_4. After the tungstic acid is filtered and washed it is purified further by the same steps used in treating the commercial H_2WO_4.

The double-purified tungstic acid is heated in silica crucibles in a gas-fired oven at 1,000° C.; the product averages 99.94 to 99.96 percent WO_3.

The method whereby the concentrates are digested with caustic alkalies is described by Gero and Iredell.[21]

Chinese wolframite concentrate is crushed so that 100 percent will pass through a 100-mesh sieve and 80 percent through a 200-mesh sieve. The pulverized ore is digested at boiling temperature with strong caustic-soda solution until decomposition is complate. The resulting sodium tungstate is decanted off and the insoluble residue washed with water. The strong sodium tungstate solution and the wash waters are combined.

Calcium chloride solution is added to the sodium tungstate solution, forming a white precipitate of calcium tungstate. This precipitate is allowed to settle and washed by decantation until free of soluble salts. The calcium tungstate, is run into an excess of boiling HCl and digested at a temperature near the boiling point.

The tungstic acid formed is allowed to settle and then washed free of soluble impurities. The tungstic acid slurry is dissolved in an excess of ammonium hydroxide, forming ammonium tungstate solution. This solution is neutralized with pure HCl, whereby fine white needles of ammonium paratungstate are precipitated; these are allowed to settle and are washed thoroughly by decantation.

The dried ammonium paratungstate crystals are ignited to volatilize the ammonia and water, leaving pure tungstic oxide containing 99.982 to 99.990 percent WO_3.

21/ Gero, W. B., and Iredell, C. V., Making Pure Tungstic Oxide Involves Many Unusual Plant Problems: Chem. and Met. Eng., vol. 35, 1928, pp. 412-417.

Acid-leaching methods are used in producing tungsten oxide from tungsten concentrates; such methods are particularly applicable to scheelite, as it is decomposed more readily by heating with concentrated HCl or HNO_3, giving calcium chloride or nitrate and tungstic acid. The filtered crude tungsten oxide is extracted with ammonium and ammonium carbonate solution, forming ammonium tungstate.22/

The ammonium tungstate is crystallized out; on ignition these crystals are decomposed, giving tungstic oxide and ammonia, which may be recovered for further use.

Tungsten ores containing tin have been fused with potassium sulphate in a muffle furnace to produce tungsten oxide.23/ After the sulphate is fused the ore is thrown in the furnace and the mass stirred continually while the temperature is increased until the entire mass is fluid enough to run out of the furnace. The solidified, fused mass is ground and treated with water, which dissolves the soluble sulphates and phosphoric acid and leaves insoluble potassium acid tungstate as a white precipitate. The insoluble residue is dried and treated with a warm solution of ammonium carbonate or cold ammonia water through which carbon dioxide is passed. The potassium acid tungstate dissolves and leaves the silica, cassiterite, and insoluble sulphates. The solution is evaporated to crystallization, which gives ammonium tungstate from which tungstic oxide is made by heating.

Production of Tungsten Powder

Tungsten powder is obtained from the trioxide by several methods the most important of which are:

1. Electric-furnace reduction with hydrogen.
2. Crucible reduction by carbon.

In the first method, purified tungsten trioxide is placed in small nickel boats, which are inserted in electric tube furnaces and heated in a current of hydrogen at 1,200° C. The tungsten forms as a gray powder. The excess hydrogen is recovered for reuse by removing the water from the exit gases.24/

In early metallurgical practice in the United States most of the tungsten powder was produced by reducing the trioxide in crucible furnaces with carbonaceous agents of various kinds. The tungsten powder produced in this way is less pure than that obtained by hydrogen reduction.

Other methods of reducing tungsten trioxide to powder have been patented or tried, such as reduction by carbon in the electric furnace and reduction by aluminum, zinc, or magnesium.

22/ Liddell, Donald M., Handbook of Chemical Engineering: McGraw Hill Book Co., New York, 1922, p. 896.
23/ Gin, G., Memoir on the Methods of Treatment of Simple and Complex Ores of Tungsten: Trans. Electrochem. Soc., vol. 13, 1908, pp. 481-541.
24/ Jones, Chester H., Manufacture of Pure Tungsten Metal: Chem. and Met. Eng., vol. 22, 1920, pp. 9-16.

Preparation of Ductile Tungsten

Before 1907 tungsten was known as a hard, brittle metal which could not be worked by mechanical means. The search for a method of producing tungsten in ductile form so that it could be drawn into fine wire for electric-lamp filaments disclosed that it lost its crystalline character by heating and working. For this purpose a very pure tungsten powder is required.

In the process of preparing ductile tungsten as described by Jones,25/ the gray tungsten powder obtained by the reduction of the oxide with hydrogen is placed under a hydraulic press and formed into bars averaging about 1 inch square and 8 inches long. These bars are placed between contacts and sintered by an electric current of 2,750 amperes and 220 volts single phase.

The sintered bars are then heated in an atmosphere of hydrogen in specially designed electric furnaces. Each furnace is a refractory alundum tube surrounded by a jacket which forms an annular space about the tube. The hydrogen introduced into this space permeates the walls of the alundum tube and enters the center of the tube where the metal bar is placed. The hydrogen then passes out through the opening through which the bar has been placed and burns in contact with air.

One end of the heated bar is drawn through a swaging machine. The bar is then reversed in the furnace and heated and the drawing operation is repeated. This cycle is continued until the bar is reduced to the required size, either as bar or heavy wire. For the finer wires used in electric lamps the tungsten is heated repeatedly, swaged, and drawn through diamond dies.

In the manufacture of sheet tungsten a swaged bar about 3/8 by 3/4 inch in section is heated in an electric furnace and rolled; the heating and rolling are continued until the bar is brought to a thick strip. As the strip becomes thinner care must be exercised during the heat to prevent excess heat from resintering the metal. By continued heating and rolling the bar is reduced to the required thickness.

Preparation of Cemented Tungsten Carbide

In the preparation of cemented tungsten carbide extremely fine tungsten powder of high purity is required. The tungsten powder is first carburized to produce tungsten carbide, by passing through a furnace containing carbonaceous gas or by heating under hydrogen intimately mixed with pure and finely divided carbon.26/

The tungsten carbide is then milled in a stainless steel ball mill with powdered cobalt, which coats each particle of tungsten carbide with a thin pellicle of that metal. Cobalt acts as the cementing material. After

25/ Jones, Chester H., work cited, pp. 13-14.
26/ Comstock, Gregory, Tungsten Carbide - The First Product of a New Metallurgy: Iron Age, vol. 126, 1930, pp. 1381-1383.

milling, the metals are compacted in a steel die under hydraulic pressure to form billets of the desired shape. These billets are heated in hydrogen at a temperature that permits enough cohesion to prevent breaking while the material is being shaped with a steel tool to the desired form. Final sintering is done in an atmosphere of hydrogen at brilliant white heat. During this last step, cementation takes place; the final product consists of particles of tungsten carbide cemented together with cobalt containing some tungsten and carbon. Except for final grinding and perhaps lapping, where a fine finish and sharp edges are desired, the product is now ready for use.

DOMESTIC TARIFF HISTORY

Before the Tariff Act of 1909, crude tungsten ores and metallic tungsten were exempt from duty under the Tariff Act of 1897. The 1909 act provided the following duties on tungsten:

> Tungsten or wolfram metal, valued at $200 per ton or less, 25 per centum ad valorem; valued at more than $200 per ton, 20 per centum ad valorem. (Par. 184.)
>
> Tungsten-bearing ores of all kinds, 10 per centum ad valorem. (Par. 190.)

Under the Tariff Act of 1913:

> Ferrotungsten***tungsten or wolfram metal***and other alloys used in the manufacture of steel, not specifically provided for, 15 per centum ad valorem. (Par. 102.)
>
> Tungsten-bearing ores of all kinds, free. (Par. 633.)

The Tariff Act of 1922 provided that:

> Tungsten ores or concentrates, 45 cents per pound on the metallic tungsten contained therein***ferrotungsten, metallic tungsten, tungsten powder, tunstic acid, and all other compounds of tungsten, 60 cents per pound on the tungsten contained therein and 25 per centum ad valorem; ferrochromium tungsten, chromium tungsten, chromium cobalt tungsten, tungsten nickel, and all other alloys of tungsten not specially provided for, 60 cents per pound on the tungsten contained therein and 25 per centum ad valorem. (Par. 302.)

The revised tariff, which became effective June 13, 1930, carried the following provisions affecting tungsten:

> ***Scrap steel, hammer scale, roll scale, and mill scale, 75 cents per ton: ***Provided further, That nothing shall be deemed scrap iron or scrap steel except secondhand or waste or refuse iron or steel fit only to be remanufactured; Provided further, That an additional duty*** of 72 cents per pound on the tungsten content in excess of two-tenths of 1 per centum, *** shall be levied, collected, and paid on all the foregoing. (Par. 301.)
>
> Tungsten ore or concentrates, 50 cents per pound on the metallic tungsten contained therein. *** (Par. 302c.)

Tungsten metal, tungsten carbide, and mixtures or combinations containing tungsten metal or tungsten carbide, all of the foregoing, in lumps, grains, or powder, 60 cents per pound on the tungsten contained therein and 50 per centum ad valorem; tungstic acid, and all other compounds of tungsten, not specially provided for, 60 cents per pound on the tungsten contained therein and 40 per centum ad valorem. (Par. 302g.)

Ferrotungsten, ferrochromium tungsten, chromium tungsten, chromium cobalt tungsten, tungsten nickel, and all other alloys of tungsten not specially provided for, 60 cents per pound on the tungsten contained therein and 25 per centum ad valorem. (Par. 302h.)

Ingots, shot, bars, sheets, wire, or other forms not specially provided for, or scrap, containing more than 50 per centum of tungsten, tungsten carbide, molybdenum, or molybdenum carbide, or combinations thereof: Ingots, shot bars, or scrap, 50 per centum ad valorem; sheets, wire or other forms, 60 per centum ad valorem. (Par. 316b.)

PHYSICAL AND CHEMICAL PROPERTIES OF TUNGSTEN METAL

The uses of tungsten metal depend on its unique physical and chemical properties. Pure tungsten metal does not have the extreme hardness which characterizes its alloys; as measured on the Mohs scale the hardness of the metal ranges from 4.5 to 8, depending on the manner of working. Relatively small quantities of some impurities appreciably affect the properties of the metal. Because of its toughness tungsten is not readily machined. It has the highest melting point (3,350° C.) of all the metals and, with the exception of carbon, the highest melting point of all substances. When worked tungsten becomes elastic and extremely ductile, so that it can be drawn into finer wire than any other metal. After working, the metal attains the highest tensile strength of any known metal, ranging from 490,000 to 610,000 pounds per square inch. As fine wire it retains its rigidity at higher temperatures than any other metal; moreover, it has the lowest vapor pressure. The density of tungsten ranges from 19.3 to 21.4, depending on the mechanical treatment it receives. The boiling point of tungsten is about 5,830° C.

Tungsten forms alloys readily with nickel, cobalt, molybdenum, uranium, chromium, iron, manganese, vanadium, and titanium and less readily with nearly all of the other metals.

Tungsten metal is not affected by oxygen at ordinary temperatures. With carbon or boron in the electric furnace it forms metallic carbides or borides of great hardness. At ordinary temperatures the metal is insoluble in hydrochloric, sulphuric, nitric, or hydrofluoric acids. Aqua regia has no effect, except to oxidize the surface of the metal to tungstic oxide. However, in a mixture of hydrofluoric and nitric acids it dissolves rapidly.

USES OF TUNGSTEN

Steel Alloys

Although tungsten has a great variety of uses its greatest use is as a component of high-speed tool steel. The value of high-speed steel for cutting purposes depends on its ability to retain its hardness when heated to redness. The use of tungsten-steel cutting tools increases the output per man and per machine enormously and results in saving millions of dollars annually. One man and one machine can do as much work with high-speed tungsten steel as five men and five machines could formerly with simple carbon steels.

One tungsten steel containing 3 to 4 percent tungsten is used for finishing cuts on iron and steel.

An important use for high-speed steel is in the manufacture of valves and valve seats for internal combustion engines, particularly airplane engines. These valves sometimes operate at red heat, and as the steel is red-hard at this temperature it gives good results.

High-speed steel is used for drawing dies in the manufacture of certain wires.

Tungsten is used in steel rails. It has been estimated that the life of rails is prolonged 5 years by the addition of 0.3 percent tungsten.

In 1900 tungsten was used for making armor plate at the Krupp Works, Germany, and the Creusot Works, France. It was also used in the manufacture of projectiles to be fired at armor plate. An alloy of 35 percent tungsten and 65 percent steel will make a shell of high penetrating power. Reduction of the caliber of guns is necessarily accompanied by diminution in the weight of projectiles. The projectiles can not exceed a certain length; beyond this limit they would no longer have sufficient stability in their trajectory. Tungsten, by virtue of its high density and hardening properties in alloys, appears desirable in the manufacture of projectiles, but its comparative scarcity precludes its use for that purpose on an extensive scale.

Tungsten has been used in steel for lining cannon, particularly by the Austrian government. Its resistance to erosion and heat increases the life and permits more rapid firing.

Tungsten is also used in steels for hacksaw blades, files, cold chisels, razor and knife blades, stamps, watch springs, strings for musical instruments, phonograph needles, sounding plates of pianos, car springs, electrical resistance wire, drills, rolls for Pilger mills, shear blades for cutting hot steel, armor for submarine cables, telephone conductors, and transformer cores.

Cemented Tungsten Carbide

Cemented tungsten carbide has created a new metallurgy and opened a new field of alloys for use of the engineer. In the past, some materials which have desirable properties have not found a wide application because of the difficulties encountered in machining with the steels available. These materials can now be machined on a commercial basis with cemented tungsten carbide tools.

Cemented tungsten carbide is offered to the trade at $450 per pound (about $1 per gram).[27] This high price is attributable to the cost of research and the present difficulties in manufacture. Being a high-priced material, it is utilized by inserting tips on steel shanks by copper brazing in an atmosphere of hydrogen or by welding. In spite of the high price, in many applications the user employs it at a distinct advantage over plain carbon-tool steels, which by comparison are as soft as lead.

Cemented tungsten carbide has been used in place of diamonds for drilling rock and can be used in place of the old-time saw teeth for cutting rock. It is also used in gages, blast nozzles, boring and reaming tools, blanking and drawing dies, and similar applications.

Nonferrous Alloys

Numerous alloys containing tungsten in conjunction with most of the metals have been invented, but the cost of the alloy is often out of proportion to its usefulness. In general tungsten in alloys usually gives hardness, and greater resistance to oxidation and corrosion.

Perhaps the most widely known nonferrous alloy of tungsten is one of the stellite alloys containing about 75 percent cobalt, 20 percent chromium, and 5 percent tungsten; other elements sometimes are added. This alloy is one of the chief competitors of high-speed tool steel. It is also used in cutlery, because it takes a high polish and is unaffected by fruit acids.

Aluminum hardened with a small amount of tungsten, called partinium, is both light and strong and is used in France for automobile construction.

Duralumin is an alloy of aluminum hardened with 2 or 3 percent tungsten and has a tensil strength of 32,000 pounds per square inch. An alloy of aluminum, copper, and tungsten is used for propeller blades. Another aluminum alloy containing 10 percent tungsten has been patented for type metal.

An alloy containing 2 to 10 percent cobalt and the balance tungsten has been patented in Germany for breeches for naval guns.

Sideraphite is an alloy containing iron, nickel, copper, aluminum, and tungsten; it resembles silver in appearance and is ductile, malleable, and resistant to corrosion.

27/ Jeffries, Zay, The Present Status of Cemented Tungsten Carbide Tools and Dies: Metals and Alloys, November 1929, p. 223.

Tungsten-nickel containing varying proportions of these two elements has been used for electric-lamp filaments.

Platinoid, an alloy containing copper, zinc, nickel, and tungsten, has been used as electrical resistance wire in filament lamps. It has a coefficient of expansion similar to that of glass.

Before the introduction of ductile tungsten many patents were issued for alloys of tungsten containing small amounts of thorium, or nickel, to be used in the manufacture of electric-lamp filaments. The addition of these metals made the tungsten ductile..

The General Electric Co. has developed a copper-tungsten electrode for welding, under the trade name of Elkonite, which does not anneal at red heat and is used for special applications where copper alone will fail.

Tungsten alloys have been suggested for jewelry. An alloy containing 75 percent gold, 10 to 15 percent tungsten, and 15 to 10 percent nickel is easily rolled and hammered and takes a fine polish. A similar alloy in which silver replaces the gold is easily polished and resists oxidation. An alloy containing 20 to 60 percent tungsten and 80 to 40 percent platinum has been patented for jewelry, electrical contacts, etc.

Tungsten-molybdenum alloys of varying composition are used as substitutes for platinum in dentistry.

A tungsten-nickel alloy carrying 75 percent tungsten and 25 percent nickel is used in hardening steel.

Other nonferrous alloys containing tungsten have been invented for, surgical instruments, electrical contact points, jewelry, pen points, high-speed bearing metals, safe and vault walls, filament supports for radio tubes, and various uses where resistance to acid liquids or vapors is desired.

Metallic Tungsten

The use of metallic tungsten for electric-lamp filaments is well known, yet this use consumes only a small part of the tungsten produced. Between 3 and 4 tons of tungsten concentrates containing 60 percent tungsten trioxide will make the filaments for 100,000,000 lamps. In the transition from the carbon to the tungsten filament numerous metals have been tried, but only a few were moderately successful. A metal suitable for incandescent lamp filaments must have a high melting point, be ductile, and possess a low vapor tension under working conditions, while its radiation must be highly selective. Waidner and Burgess[28/] have shown that the light emitted by an incandescent metal varies as the twelve power of the temperature, and the energy required varies as the fifth power of the temperature. An increase in the working temperature is therefore very important.

28/ Waidner, C. W., and Burgess, G. K., U. S. Bureau of Standards, vol. 2, 1907, p. 319.

According to Zay Jeffries:29/

In the present state of the electric-incandescent-lamp art the average efficiency during the life of a tungsten-filament lamp is 4 1/2 times that of the carbon-filament lamp. Leaving out of consideration miniature lamps, there are consumed annually in the United States alone over 15 billions of kilowatt-hours of electrical energy for illumination at a cost to the consumer of approximately $800,000,000. If the same level of illumination were maintained in the United States by the use of carbon lamps, assuming the same average cost of electrical energy to the consumer, an additional expenditure of about $2,900,000,000 would have to be made. Incidentally this amount of money would more than buy all the pig iron and nonferrous metals produced in the United States in a year. It is of course obvious that if we were still using carbon lamps we would not enjoy the present level of illumination. If we had, however the present level of illumination with carbon lamps, and assuming that no other material except tungsten to be available to replace carbon, we could afford to pay about $330,000 per pound for tungsten and still obtain our light at the same cost. The actual cost of tungsten at the present time, in the ore, is less than a dollar a pound. This is only one illustration of the general proposition that the cost of a metal to the consumer is a function of its concentration in the earth's crust and its ease of recovery rather than its value to industry.

Inasmuch as drawn tungsten wire has a high tensile strength and can be drawn into wire having a diameter of 0.0004 inch it has been used for galvanometer suspension, cross hairs in telescopes, radio tubes, rectifying valves, X-ray tubes, and surgical wire, replacing gold and silver wires. Tungsten wire is an excellent material for wiring electric furnaces on account of the high temperature maintained.

Tungsten is used for making vacuum seals through special glass with a coefficient of expansion approximating that of tungsten.

Tungsten contact points are used in spark coils, voltage regulators, telegraph keys, and similar devices in place of platinum-iridium formerly used. The cost of platinum for such uses is much higher than the cost of tungsten. Sheet tungsten has been found to be a very efficient metal for the construction of amplifiers in wireless apparatus.

Tungsten electrodes are used in certain electrochemical processes where resistance to corrosion is desired.

Tungsten-molybdenum thermocouples are used for measuring high temperatures as the electromotive force increases with an increase in temperature.

Tungsten gauze resists acids and alkalies; it is used in separating liquids from solids where corrosion is a factor. It has also been used in some of Cottrell apparatus for the electrostatic precipitation of fumes.

29/ Jeffries, Zay, Engineering and Science in the Metal Industry: Mech. Eng., vol. 48, 1926, p. 8.

Tungsten crucibles have been used in vacuum furnaces or in furnaces filled with inert gases. Laboratory apparatus has been made from wrought tungsten where resistance to corrosion is desired.

Since tungsten has high specific gravity, high heat conductivity, high melting point, and low vapor pressure tungsten buttons brazed to copper have been used as anticathodes in Roentgen (X-ray) tubes.

Recently tungsten was deposited from an alkaline solution by electrolisis;30/ its use in electroplating may open a wide field. The tungsten deposited from aqueous alkaline solutions is smooth, hard, and coherent and has a high luster. Like chromium, it needs no polishing if the plated articles were previously polished. Because of its acid-resisting properties tungsten is useful as a coating for other metals.

Tungsten has also been used as a catalyst in the production of ammonia from nitrogen of the air.

Chemical Compounds

Sodium tungstate is used as a mordant in dyeing, for rendering cloth noninflammable, for weighting fabrics such as silk, in painting, for decolorizing acetic acid and acetates prepared from pyroligneous acid, and as a decorticator in preparing raw fibers for manufacturing.

Fluorescent cadmium tungstate is used in making fluorescent screens for visual observation in X-ray practice; considerable fluorescent calcium tungstate is employed in making intensifying screens for X-ray photography.

Lead, zinc, and barium tunstates are used as substitutes for white lead.

The pure oxide is used as an oil and water color and when converted into blue oxide is used as a pigment. The oxide also is employed in ceramics to produce various shades of yellow in glass and porcelain.

The so-called tungsten bronzes are made by fusing an alkali tungstate and pure tin. Various shades of red, yellow, or blue are thus formed and used for decorative purposes.

Yellow, blue, green, pink, and gold tungsten salts are employed in the manufacture of stained papers.

MARKETING TUNGSTEN CONCENTRATES

The value of tungsten concentrates is determined by the tungsten content invariably expressed in terms of tungsten trioxide.

30/ Fink, Colin G. and Jones, Frank L., The Electrodeposition of Tungsten from Aqueous Solutions: Trans. Electrochem. Soc., vol. 59, 1931, 23 pp. (preprint).

The term "unit", when used in stating the price of tungsten concentrates, is synonymous with percent of WO_3. Marketing tungsten concentrates on the unit basis is prescribed by custom. A unit representing 1 percent tungsten trioxide in 1 ton of concentrates may be 20, 22.4, or 22.04 pounds, depending on the size of the ton (short, long, or metric). In the United States prices are quoted in short-ton units, whereas in the British Empire they are quoted in long-ton units. France and Germany employ the metric-ton unit.

There is no standard for setting a price on tungsten concentrates; beyond a general quotation on concentrates containing 60 percent WO_3 selling is subject largely to supply and demand bidding. In general, tungsten concentrates must contain at least 60 percent (60 units per short ton) tungsten trioxide to be salable; moreover, they must be relatively free from such impurities as antimony, arsenic, bismuth, copper, lead, manganese, nickel, phosphorus, tin, zinc, and sulphur. All buyers do not object to the same impurities in the concentrates; and sometimes in a brisk market off-grade ores can be sold, but at a discount. Ores from different districts often are quoted at different prices, and no definite scale of premiums and penalties has been fixed. The grade of concentrates desired by consumers depends on the method of converting and the use to which the tungsten metal or compound is to be put. Tungsten concentrates used in the manufacture of alloy steels and for conversion into metal are subject to rigid requirements as to impurities. The following quality guarantee, required by some manufacturers, illustrates in a general way the requirements:

	Percent
Tungsten trioxide	65-70
Tin (maximum)	Trace
Arsenic (maximum)	0.035
Antimony (maximum)	.035
Bismuth (maximum)	.035
Copper (maximum)	.05
Sulphur (maximum)	.75
Phosphorus	.05

If requirements as to deleterious elements were not rigid the quality of the finished alloys might be impaired or even destroyed by their presence.

Production of tungsten concentrates in the United States is characterized by many actual and potential producers, only a few of whom are well-financed. There is no tendency toward an integrative policy whereby the consumer is also the producer; only one tungsten-mining company at present is affiliated with consuming interests.

Since tungsten ores are not exploited on a large scale the market is unstable. Moreover, there are no effective organizations of buyers or sellers, so that domestic producers must deal either through brokers or direct with consumers by private negotiations.

Tungsten concentrates usually are sold in carload lots (35 tons), and if the market is heavy smaller lots are difficult to sell.

Concentrates are sold on a custom assayer's certificate of weighing, sampling, and analysis. No legal or trade rule requires buyers or sellers to bear this cost; generally they share it by mutual agreement.

Before 1918 ferberite was preferred to scheelite, but changes in the practice of using tungsten concentrates created a larger demand for the latter. For reduction of tungsten minerals to metal or ferrotungsten high-grade concentrates are required because the capacity of the electric furnace in which they are reduced is limited. From the viewpoint of metal content in the economic tungsten minerals scheelite contains the most tungsten. Taking scheelite as 100 the tungsten content of the four principal tungsten minerals is as follows:

Scheelite	100
Ferberite	98.5
Wolframite	96.5
Hübnerite	90.0

Marketing of tungsten concentrates has been hampered in the past by a lack of standard requirements, the wide territory over which the deposits are distributed, and lack of centralization in buying or selling.

STRATEGIC IMPORTANCE OF TUNGSTEN AS A WAR MINERAL

Due to the unique role of tungsten in our economic structure it is one of the pivotal war minerals. Since the comparative efficiency of tungsten-alloy cutting tools is 3 to 5 times that of carbon steel the large amounts of lathe-turned, drilled, or planed steel required for armaments in the World War could hardly have been produced by the use of carbon-steel tools. Consequently tungsten is a vital necessity to the welfare of the country in a time of national emergency.

Germany was the only nation that properly appraised the importance of tungsten as a strategic war mineral before the World War. At that time she virtually monopolized the production of ferrotungsten; tungsten concentrates produced in various parts of the world were shipped to Germany for fabrication into high-speed steel. With characteristic thoroughness Germany developed tungsten mines in various parts of the world, including the United States, Peru, Bolivia, Argentina, and Burma. The position of the ferrotungsten industry before the war was one of the most striking examples of Germany's industrial domination of a raw material she herself almost wholly lacks. In 1913 Germany produced only 1 percent of the world output of tungsten ore yet she controlled 60 percent of it.[31/] Great Britain through her possessions produced 37 percent of the world output, yet she depended on Germany not only for ferrotungsten but also for her tungsten-steel tools, which even though purchased through English firms were derived from German manufacture.

31/ Bliss, Eleanora F., Some Problems of Readjustment of Mineral Supplies as Indicated in Recent Foreign Literature: Econ. Geol., vol. 14, 1919, p. 166.

In 1913 France produced 12 percent of the world output and in addition controlled the production of a mine in Portugal and held an interest in the Bolivian enterprises. Owing to her development of water power she had a prewar production of ferrotungsten, although she was not in position to compete with the German output of ferro-alloys or high-speed tools.

In the United States before the war only a few technical men realized the importance of tungsten as an essential ingredient in the manufacture of tool steel and as a cornerstone of mass production of munitions. Tungsten was unknown to the man in the street; the major part of our tool-steel requirements was imported to meet industrial needs.

When the war broke out the manufacturers of high-speed tool steel in England found themselves without an adequate supply of tungsten, owing to German control. Establishment of the tungsten industry was of paramount importance; following Government inquiry a committee of leading English steel manufacturers was formed, and 31 firms took shares in the company organized, the High-Speed Steel Alloys (Ltd.). In September 1915 the British Government assumed control of the production of tungsten ores within the Empire and apportioned them among the makers of ferrotungsten.

This British embargo on tungsten was reflected in the United States, when munitions manufacturers realized that tungsten steel was unobtainable. The steel manufacturers sent men scurrying over the world to purchase ores and concentrates; domestic search for additional tungsten deposits was so stimulated that many new deposits were found. Although the domestic production of tungsten concentrates jumped from 2,332 tons in 1915 to 6,144 tons in 1917 the supply was inadequate to meet the emergency requirements.

In order that the domestic supply of tungsten shall be adequate in time of war the following suggestions have been proposed:

1. Substitute other metals for tungsten.

2. Cessation of domestic production and reservation of the deposits solely for emergency use.

3. Accumulation and maintenance of a reserve supply of tungsten concentrates.

4. Stimulation of domestic production by tariff protection.

In discussing substitutes for tungsten peace-time requirements of comparative costs need not be considered; war conditions impose quantity and quality. Assuming that the resources of tungsten ores in the United States are inadequate for war purposes, the number of substitutes available are limited. The principal substitute suggested and tried is molybdenum, but it was not as satisfactory as tungsten in high-speed steel. Taylor[32/] found that molybdenum

32/ Taylor, F. W., On the Art of Cutting Metals: Trans. Am. Chem. Soc., vol. 28, 1906, pp. 31-35.

steels for cutting purposes caused irregular performance; that steels of nearly the same composition and receiving the same treatment varied considerably in cutting speeds. More extensive research on the metallurgy of molybdenum has overcome these difficulties. Ritchie[33] has announced that molybdenum can be substituted in whole or in part for tungsten in high-speed tools and that all difficulties in the manufacture of molybdenum high-speed tools can be overcome.

If molybdenum can be substituted for tungsten in high-speed steels it must rank as a competitor of tungsten under normal industrial conditions to be available quickly in time of a crisis, since war-time applications of the metals are largely an extension and expansion of their peace-time applications. In general, the major difficulty in substituting other metals for war minerals is the fact that the metal for which substitution is to be made usually is the one that accomplishes the desired results. Introduction of molybdenum for tungsten during a crisis would involve a change in technic which might result in the loss of considerable time. Molybdenum eventually may displace tungsten but the extent of its use in high-speed steel under normal working conditions cannot be predicted.

Other alloys containing zirconium, uranium, vanadium, and tantalum have been developed as substitutes for tungsten in high-speed steels, but the comparative scarcity and cost of these metals will no doubt prevent their extensive application.

Substitutes for cemented tungsten carbide cutting tools are possible but as yet have not been developed to the same extent as tungsten. The other hard metal carbides are titanium, zirconium, thorium, vanadium, niobium, tantalum, chromium, molybdenum, and uranium. As this new branch of metallurgy develops one of these hard-metal carbides may be found to be a commercial competitor of tungsten.

It has been proposed that peace-time demand for tungsten should be derived from foreign sources and thus conserve domestic resources for a national emergency. Inasmuch as all extraction of ore is depletion and cannot be replaced this plan would be advantageous if domestic resources were small and the supply immediately available during a crisis. Only through Government control could this plan be carried out. Industrial development in the United States, however, has been intrusted to the control exerted by the natural law of supply and demand working under free competition. Although plausible in theory, Government ownership of the tungsten resources is not likely to appeal to the American people.

If domestic resources of tungsten ores are to act as a safeguard in an emergency they must be available when the emergency arises. Even though the deposits are conserved their availability cannot be assured unless the time-consuming mine and process development and plant erection have reached the production point before the emergency arrives. Economically such a course is impracticable, as the very essence of a program of preparedness is to obviate

33/ Ritchie, S. B., Molybdenum in High-Speed Steel: Army Ordnance, vol. 11, July-August 1930, pp. 12-19.

all delays. Then, too, solicitude for the welfare of the future can be carried to extremes, inasmuch as there is no assurance that present technic in the production of tungsten products will be permanent.

Accumulation and maintenance of a stock-pile reserve of tungsten concentrates for emergency use have so far been contrary to American policy. The size of the stock pile would depend on the requirements of the essential industries using the raw material and the length of time imports would be restricted or cut off.

Whether or not the tungsten industry should be protected by tariff is a moot question. Without tariff protection the mining of tungsten ores in this country could not survive, as was demonstrated from 1918 to 1922, when imports of tungsten ores brought the domestic production to a standstill. The opponents of a Government subsidy in the form of a tariff base their opposition largely on the supposition that domestic resources of this metal are too limited to justify a duty and should be conserved for national emergency. Our tungsten resources are larger than is generally supposed. Many low-grade deposits of tungsten ores have been discovered in this country within the last 15 years, and only about 25 percent of these have been prospected. Further development of these deposits probably will disclose important new discoveries and extensions to the known deposits, as judged by past history of the mining industry.

In the final analysis the problem resolves to the question of the insurance premium the country is willing to pay to reduce the risk of being wholly dependent on foreign countries for tungsten needs in time of national emergency.

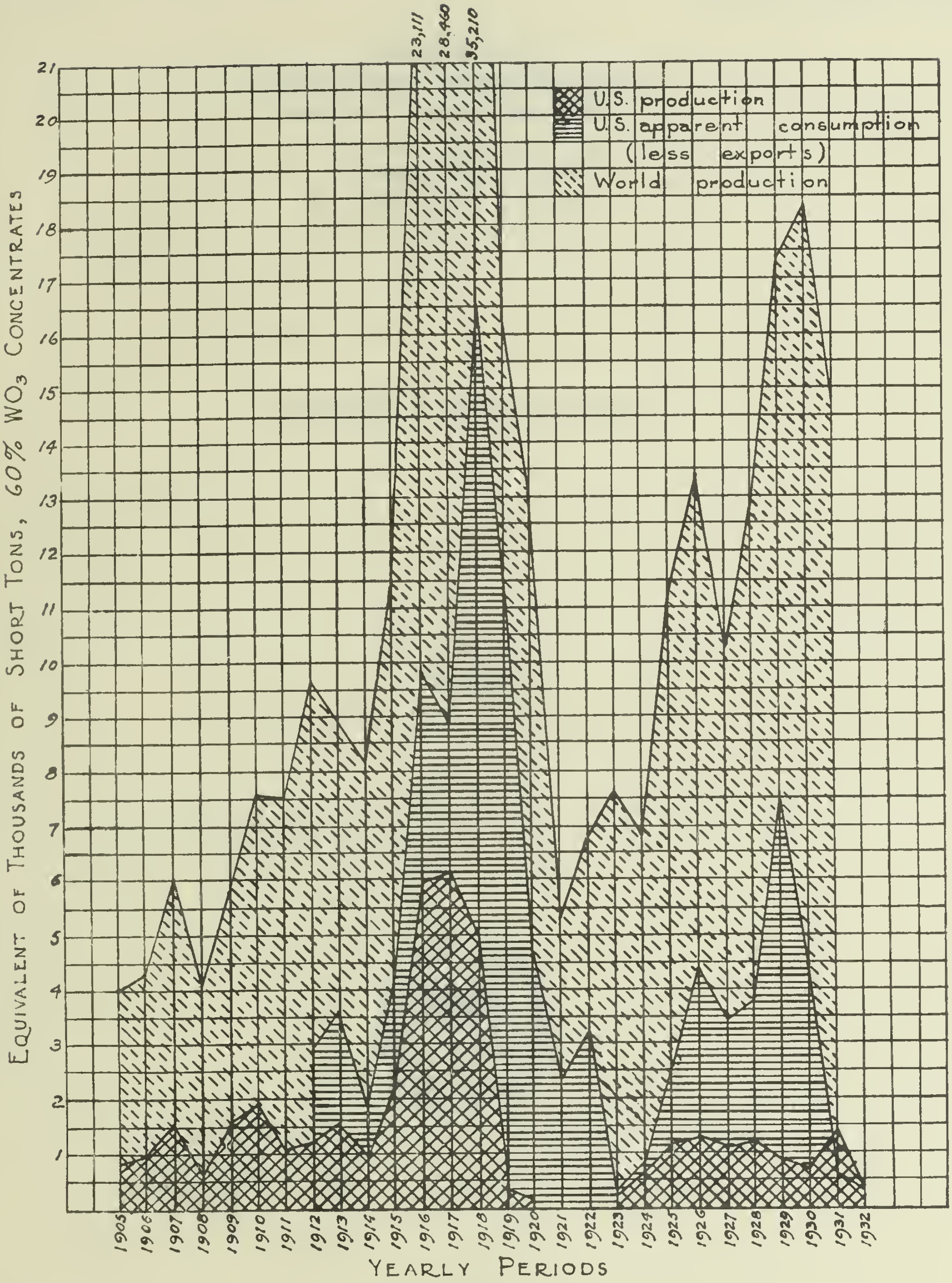

Figure 1.- World production and production and apparent consumption in the United States of tungsten, 1905-32, in short tons containing 60 percent WO_3.

I. C. 6822

April 1935
Revised August 1941

UNITED STATES
DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

BUREAU OF MINES
R. R. Sayers, Director

INFORMATION CIRCULAR

MICA

BY

F. W. Horton

I.C.6822,
April 1935
Revised August 1941

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

MICA[1]

By F. W. Horton[2]

CONTENTS

1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S Bureau of Mines Information Circular 6822."

2 Mining engineer U. S. Bureau of Mines.

CONTENTS (Cont'd.)

INTRODUCTION

This paper covers the salient features of the occurrence and mining of sheet mica in the United States and the preparation of mica for market; presents the results of a study of the physical properties of domestic and foreign micas, which the author hopes may be of interest to every mica user, as it definitely answers many questions as to the suitability of various micas for particular purposes; and discusses mica-trade conditions and the future outlook for the domestic mica industry.

ACKNOWLEDGMENTS

The author takes pleasure in acknowledging his indebtedness to J. R. Thoenen, of the United States Bureau of Mines, under whose guidance the work reported herein was performed, and to Frank L. Hess, also of the Bureau, for information on the geological and mineralogical characteristics of mica-bearing pegmatites.

Special acknowledgment is due the late Dr. George K. Burgess, former director of the National Bureau of Standards, and to Dr. L. J. Briggs, the present director, for providing the facilities of their organization in performing the physical tests described herein. The author is also indebted to the following physicists of the Bureau of Standards, who directed and performed the tests: Dr. F. B. Silsbee, A. B. Lewis, F. R. Caldwell, and E. L. Hall.

Thanks are due to Dr. O. E. Kiessling and B. H. Stoddard, of the United States Bureau of Mines, for their kindness in supplying data on the production and consumption of mica.

Acknowledgment is made to all individuals and companies who supplied micas for physical tests, allowed the writer to examine their mica deposits and mica-working plants, or otherwise assisted him.

Valuable help was given the writer by Herbert Brown, J. Fuller Brown, and B. C. Grindstaff, of the Asheville Mica Co., Biltmore, N. C., in studying the mica deposits of North Carolina. The writer is also indebted to Douglas B. Sterrett, Joseph Ulmer, and W. M. Myers for much information that has been taken from their respective reports on various phases of the mica industry.[3]

HISTORY OF THE MICA INDUSTRY IN THE UNITED STATES

Ornaments made from mica found in graves of the mound builders in the Mississippi Valley and extensive aboriginal workings in the Southern Appalachian States offer conclusive proof that mica was mined in the United States before the arrival of white men. Mining, of course, was restricted to the weathered portions of pegmatites in which the feldspars had been kaolinized and the rock rendered soft enough to be mined with primitive tools. What peoples engaged in this ancient mining or what uses were made of the mica are unknown, but it is assumed that the mica was used largely for ornaments. In Europe mica has been used for 2 or 3 centuries as glazing for windows, and in India for even longer in making lanterns and ornaments and as a medicine.

In the United States the Ruggles mine in Grafton County, N. H., which was opened in 1803, was the first known mica deposit operated on a commercial scale. The product was utilized almost exclusively for stove windows. Soon afterward other deposits were opened in New Hampshire, and mining was carried on irregularly until shortly after the Civil War, when

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3 Sterrett, D. B., Mica Deposits of the United States: U.S. Geol. Survey Bull. 740, 1923, 342 pp.
Ulmer, Joseph, International Trade in Mica: Bureau of Foreign and Domestic Commerce, 1930.
Myers, W. M., Mica. Pt. I, General Information: Inf. Circ. 6205, Bureau of Mines, 1929, 37 pp.

the first large-scale production was made in North Carolina and mining in New Hampshire declined. North Carolina continued to be the leading producer of mica for many years, although intermittent mining of mica on a considerable scale has been carried on in many other States, notably Virginia, South Dakota, New Mexico, Idaho, Georgia, and Connecticut. During the last decade New Hampshire has alternated with North Carolina as the leading producer of sheet mica; the production of scrap grades in North Carolina, however, has far exceeded that in New Hampshire.

Although the United States is the world's largest consumer of mica, its market for sheet mica has been dominated for 40 years by imports from India, except for brief periods during which import tariffs were high enough to prevent such control. India has excellent deposits of mica and exceedingly cheap labor, which has been utilized in making a splendidly prepared and closely graded mica with which the domestic product cannot compete on an even basis. The process of making mica plate or mica board by cementing thin films or splittings of mica with shellac or other suitable binders was discovered in 1894, and as the built-up board was easily fabricated it gave considerable impetus to the use of mica in the electrical industries.

Because of its cheap labor and supplies of suitable mica, India immediately captured the world market for splittings and today produces virtually all muscovite splittings used in the United States and Europe. Various methods of splitting mica by machine have been devised, but none has been notably successful in splitting muscovite. For several years a small production of phlogopite or amber splittings has been made in the United States by machine methods from mica recovered from Canadian mine dumps, but the bulk is produced by hand from Madagascan and Canadian phlogopite. The domestic mica industry exists today solely by virtue of a protective import tariff.

GENERAL DESCRIPTION OF MICA

The term "mica" from the Latin "mico", meaning to sparkle or glisten, is a group name for a number of aluminum silicate minerals characterized by their high reflection and a basal cleavage so perfectly developed that they can be split into exceedingly thin laminae, which are more or less tough, elastic, and transparent according to variety. The micas are primarily silicates of aluminum with potassium (or sodium) and hydrogen; all yield water on ignition, usually 4 to 6 percent. They often contain magnesium and ferrous iron and in certain instances sodium, lithium, chromium, and ferric iron. Fluorine is prominent in some species and probably occurs in most if not all of them. Barium, manganese, titanium, and boron occur in some varieties. Mineralogists recognize 8 distinct species of true mica, as shown in the following table, but of these only the first 5 are commercially important.

Species	Theoretical chemical formula
Muscovite	$H_2KAl_3(SiO_4)_3$
Phlogopite	$HK\ (MgF)\ _3Mg_3Al(SiO_4)_3$
Biotite	$(HK)_2(MgFe^{II})_2(AlFe^{III})_2(SiO_4)_3$
Lepidolite	$KLi\ Al(OHF)_2\ Al(SiO_3)_3$
Roscoelite	$H_8K(MgFe)(AlV)_4(SiO_3)_{12}$
Zinnwaldite	$(KLi)_3FeAl_3Si_5O_{16}(OH,F)_2$?
Paragonite	$H_2NaAl_3(SiO_4)_3$
Lepidomelane	$HK_2F_3{}^{II},\ Fe_6{}^{III}6Al3(SiO_4)_9$

Most of these formulas have not been definitely established; in fact, all species of mica vary considerably in composition, giving rise to numerous varieties. However, the for-

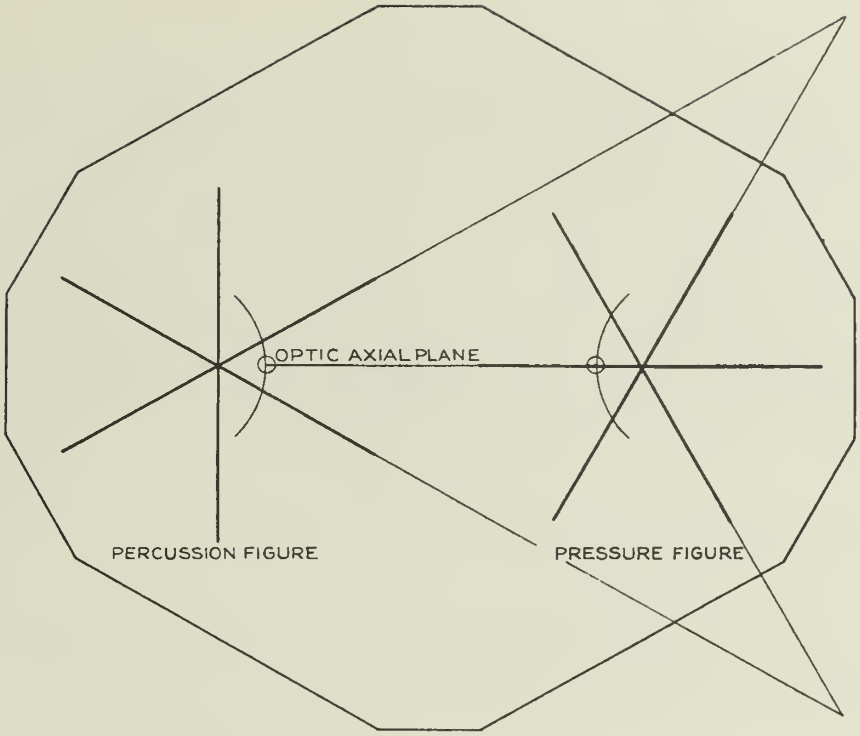

Figure 1.—Positions of the percussion and pressure figures in muscovite. (After W. T. Schaller.)

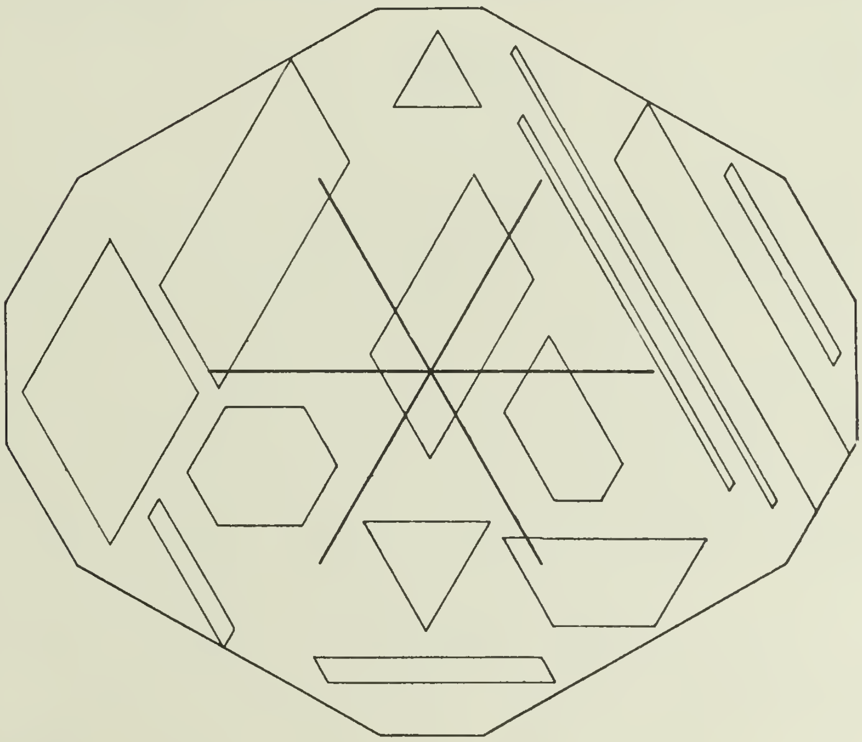

Figure 2.—Outlines of all polygons formed by parting planes in muscovite follow the direction of the rays of the pressure figure. (After W. T. Schaller.)

mulas show the approximate composition of the typical species and indicate why muscovite is commonly called potash mica; biotite, iron mica; lepidolite, lithium mica; and paragonite, sodium mica in accordance with the prominence of these elements in the micas. Mica crystallizes in the monoclinic system but with a close approach to either rhombohedral or orthorhombic symmetry. In all cases the plane angles of the base are close to 60° or 120°. A cleavage plate shows an axial interference figure which for pseudorhombohedral micas is uniaxial or nearly so, as with biotite. The axial angle of phlogopite is usually 10° to 12°, but for muscovite, lepidolite, and paragonite the angle is commonly 50° to 70°. All species of mica may be referred to the same fundamental axial ratio with an angle of obliguity varying but slightly from 90°. They commonly show the same forms and frequently intercrystallize in parallel position. Thin sheets of muscovite containing areas of biotite or vice versa are common; lepidolite and muscovite intercrystallize in the same way.

A six-rayed percussion figure is produced in all micas by striking a cleavage plate with a small, dull point. A dulled pin struck sharply on the head will produce the figure in a thin plate. Two lines of the figure approximately parallel the prismatic edges of the crystal, and the third or strongest parallels the clinopinacoid. The percussion figure may be used to establish the crystallographic orientation when crystal faces are lacking.

A second series of lines at angles of about 30° with those of the percussion figure may be developed more or less distinctly by pressure of a dull point on a thin lamina, forming the so-called pressure figure.

Of the five commercial micas muscovite, phlogopite, and biotite are used solely because of their physical properties, whereas lepidolite and roscoelite are mined as ores of lithium and vanadium, respectively.

MUSCOVITE

Mineralogy

Muscovite or potash mica is the most important mica of commerce and is the only one mined extensively in the United States. It usually occurs as tabular crystals, hexagonal or rhombic in outline, with prismatic faces more or less rough and striated horizontally. These crystals may be 4 or 5 feet in diameter and weigh 1 or 2 tons, or they may be less than 1/16 inch across, aggregated in stellate, feathery, or globular forms. In fact, the crystals may be cryptocrystalline. Muscovite has an eminent basal cleavage and also secondary cleavages, better described as parting planes, which cut the crystals at angles of 60° to 70° with their basic cleavage. These parting planes may extend entirely through a crystal or only part of the way either across the cleavage face or through the thickness of the crystal. Figure 1[4] shows the positions of the percussion and pressure figures of muscovite with respect to the crystal faces and to each other. Figure 2[5] shows that the outlines of the ribbons, triangles, acute rhombs, and other polygons formed by parting planes follow the direction of the rays of the pressure figure and not of the percussion figure.

Thin laminae of muscovite are transparent, flexible, elastic, and usually colorless. Sheets 1/8 inch or more in thickness, however, usually show a distinct color - some shade of gray, brown, red, yellow, or green. The color, probably due to minute inclusions of metallic oxides, classifies the mica as "ruby", "rum", "green", "smoked", etc. Zonal coloration with a definite relation to crystal structure is found occasionally.

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4 Schaller, W. T., U.S. Geological Survey Report D-269 to Scott Turner, Director, U.S. Bureau of Mines, Oct. 30, 1933.
5 See footnote 4.

Muscovite ranges in hardness from 2 to 2.5. The harder varieties usually are less flexible than the softer, which has a direct bearing on the suitability of the mica for certain uses. Muscovite has a specific gravity of 2.76 to 3, a colorless streak, and commonly a vitreous luster. The index of refraction ranges from 1.56 to 1.59. Muscovite is optically negative and normally has an axial angle of about 70°, which diminishes to 50° in varieties high in silica. Usually it is feebly pleochroic, but in some deep-colored varieties pleochroism is pronounced. It has a rather strong double refraction.

Muscovite shares with phlogopite the reputation of being the best dielectric known and is an excellent thermal insulator. Under normal conditions it is one of the most stable of minerals. It is virtually unaffected by weathering and is not decomposed by acids. It may be heated to 400°C. without change; at this temperature, however, it begins to give up minute quantities of its water of crystallization, and at 700°C. normal muscovites lose about 1/10 percent of their weight. As dehydration progresses the mica swells, loses its transparency, and becomes brittle.

The following table shows analyses of typical muscovites:

TABLE 1.- Composition of muscovite from various localities[1]

	Theoretical	Alexander County, N. C.	Auburn, Maine	Haddam, Conn.	Bengal, India
SiO_2..	45.2	45.40	44.48	45.05	45.57
Al_2O_3	38.4	33.66	35.70	30.57	36.72
K_2O....	11.8	8.33	9.77	10.23	8.81
Na_2O..	....	1.41	2.41	2.13	.62
Fe_2O_3	....	2.36	1.09	1.14	.95
FeO....	....	....	1.07	1.73	1.28
MgO....	....	1.86	Trace.	.97	.38
CaO....	....	....	0.10	....	.21
Li_2O..	....	....	....	....	.19
TiO_2..	....	1.10	....	....	....
F........	....	.69	.72	1.26	.15
H_2O....	4.6	5.46	5.50	6.19	5.05
	100.0	100.27	100.84	99.27	99.93

[1]Dana's System of Mineralogy, 1911, pp. 617-618.

Among the many varieties of muscovite sericite is perhaps the most common. It is a fine, scaly muscovite characterized by its silky luster and unctuous feel. It is sometimes united in fibrous aggregates and is generally regarded as of secondary origin, derived from the alteration of feldspar, kyanite, and many other aluminum silicates.

Fuchsite is a green chrome muscovite usually containing 2 to 4 percent of chromic oxide.

Occurrence

Muscovite is the most common of the micas; as an essential constituent in all granites, gneisses, schists, and other related rock it occurs in huge quantities. However, it rarely has commercial value in these forms, as it usually cannot be recovered economically. A few schists exceptionally rich in muscovite (or sericite) are milled for their mica content, and a considerable quantity of fine muscovite is recovered as a byproduct from kaolin deposits in North Carolina formed by the weathering of aplites of which the mica was an original constituent. With these exceptions all commercial muscovite is derived from pegmatites, the

sole source of sheet muscovite the world over; the genesis, occurrence, and mineralogy of this interesting class of rock therefore will be discussed briefly.

Inasmuch as freedom from ruling, folding, and distortion is an essential of good sheet mica, the geologic history of regions in which mica-bearing pegmatites occur is important. Movement of the enclosing rocks either during or after the formation of mica has often rendered it valueless except for scrap through the development of ruled, wedge, tangle-sheet, and other imperfect forms. The best sheet mica is invariably found in regions of geologic stability.

Pegmatites

Pegmatites have been defined as "rocks with coarsely and unevenly crystallized and segregated minerals occurring as dikes, veins, or metamorphic masses formed from the aqueous solutions of a freezing magma or from the combination of the solutions with previously existing minerals.[6] They were the drainage systems of freezing batholiths of granite rocks that formed wet melts, whose freezing was accompanied by the expulsion of watery solutions in either gaseous or liquid form. These solutions first deposited the granitoid minerals - potash, feldspar, and quartz and in some instances muscovite or biotite or both of these micas; but in this primary form of pegmatites the mica crystals, if present, are never large enough to yield sheet mica. Owing to the long-continued flow of the solutions and possibly to changes in their character, extensive replacements of the original minerals of the pegmatites have taken place. In the replacement processes large crystals of muscovite, biotite, and sometimes lepidolite were formed, and many other minerals were introduced. Common examples are albite, tourmaline, beryl, lepidolite, spodumene, amblygonite, pollucite, cryolite, cassiterite, apatite, garnet, epidote, uranium, tantalum, and columbium minerals.

Pegmatites in which replacement has taken place are classified by Hess[7] as "metamorphic pegmatites"; this type is the sole source of sheet muscovite.

In shape and size pegmatites vary greatly. They may be dikes and veins up to 1 mile or more long and 300 feet wide, or they may be lenses, oval masses, or pipes as much as several hundred feet across or possibly only a few inches. Their mineralogical composition may change with the rocks traversed, and in metamorphic pegmatites the order of replacement may be completely reversed within a few rods. Two characteristics, however, are common to all pegmatites - coarseness of texture and a notably uneven segregation of their constituent minerals.

The generally accepted belief is that all muscovite crystals large enough to yield sheet mica were formed by hydrothermal action of a mineralized solution on an original pegmatite consisting of potash, feldspar, and quartz. This belief in the replacement origin of large muscovite is borne out by (1) the frequent occurrence of the crystals in zones along the hanging wall or both walls of the pegmatite containing them or along cracks or planes of weakness, (2) the fact that the crystallization of the muscovite is not finer near the walls as would be expected through quicker cooling from contact with the walls if the crystals were deposited from the original injection, (3) the occasional occurrence of large mica books in the wall rock, and (4) the general similarity of the petrographical characteristics of pegmatites containing large muscovite to replacement veins and contact-metamorphic deposits. Anderson[8] states that evidences of replacement, especially the presence of albite, should serve as a guide in prospecting for mica and that those pegmatites that show little

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6 Hess, Frank L., Pegmatites: Econ. Geol., vol. 28, August 1933, pp. 447-462.

7 See footnote 6.

8 Anderson, Alfred L., Genesis of the Mica Pegmatite Deposits of Latch County, Idaho: Econ. Geol., vol. 28, no. 1, p. 57.

replacement should not be considered probable commercial sources of sheet mica. On the other hand, if a pegmatite presents ample evidence of hydrothermal action it probably contains large mica crystals and should be prospected along the channels of replacement. These channels rarely extend throughout the pegmatite; masses of the original graphic granite may constitute a large part of the deposit. Replacement usually is confined to zones along either or both walls of the pegmatite or to channels through the mass, which probably followed cracks or planes of weakness. In many places the replacing solutions have entered the wall rock, and large muscovite crystals may have been deposited there with all the other minerals occurring in the pegmatite proper.

W. T. Schaller of the United States Geological Survey, in a personal communication, points out that the formation of large muscovite usually followed closely and sometimes accompanied the albitization, which represents the first stage of the replacements, and that much replacement may have taken place after the muscovite was formed. However, extensive replacement is not always an indication of the plentiful occurrence of large muscovite crystals in a pegmatite.

PHLOGOPITE

Mineralogy

Phlogopite, more generally known as amber or magnesia mica, is second to muscovite in commercial importance but finds some special uses where it gives superior service. It occurs in monoclinic crystals which usually are six-sided prisms with irregular and tapering sides. The crystals range from minute particles to 4 feet in diameter, although such large specimens are rare. Phlogopite ranges from colorless and silvery white through shades of yellow, brown, and sometimes green to almost black. It has a pearly to submetallic luster on cleavage surfaces, with a coppery reflection which gave rise to its name, derived from the Greek, phlogopos, firelike.

Phlogopite has a highly eminent basal cleavage; the light-colored varieties can be split into thin, elastic folia as readily as muscovite. Dark phlogopites, however, cannot be split as easily as the light varieties, nor are they as good dielectrics.

The color of phlogopite often indicates its hardness, which ranges from 2.5 to 3; the darker kinds are notably harder than the light-colored ones. Variation of hardness with color is particularly notable in Madagascan phlogopites. According to the figures given here, phlogopite is harder than muscovite; but these figures apparently do not coincide with the experience gained from the use of these two micas in insulating commutator segments. For this use phlogopite is preferable because it wears down evenly with the copper and does not form projecting ridges. However, this more rapid wearing of phlogopite compared with muscovite is probably attributable to its greater friability rather than to any inferiority in hardness. Phlogopites, particularly light-colored varieties, are more resistant to heat than muscovites and will stand a temperature of 800° without appreciable dehydration, probably because they contain less water of crystallization.

Phlogopite in thin folia is transparent to translucent and often exhibits asterism in transmitted light due to regularly arranged inclusions. Asterism is particularly prominent in Canadian phlogopites. Its index of refraction ranges from 1.56 to 1.61. In sheets an eighth of an inch or more thick phlogopite is opaque. Its specific gravity is virtually the same as that of muscovite, ranging from 2.74 to 2.95. Unlike muscovite, however, it alters readily, losing its elasticity and assuming a high pearly luster, often with brownish spots as if from hydration of iron oxide. Like biotite, which approaches it closely in character and composition, it often alters to vermiculites. It is completely decomposed by sulphuric acid, leaving thin porous scales of silica.

Figure 3.—Location of principal muscovite deposits of the United States and phlogopite deposits of Canada.

Schaller[9] states that the relations and crystallographic positions of the percussion figure, pressure figure, and parting planes are identical in muscovite and phlogopite. The optic axial planes in the two micas, however, are normal to each other.

The following table shows the composition of phlogopites from various sources.

TABLE 2.- Composition of phlogopite from various localities[1]

	Edwards, N.Y	Burgess, Ontario	Ratnapura, Ceylon
SiO_2....	40.64	39.66	42.26
Al_2O_3..	14.11	17.00	15.64
MgO......	27.97	26.49	27.23
K_2O......	8.16	9.97	8.68
Fe_2O_3..	2.28	.27	.23
FeO......	.69	.20	1.52
BaO......	2.54	.62	....
Na_2O....	1.16	.60	....
TiO_2....	....	.56	....
F.........	.82	2.24	2.19
H_2O......	3.21	2.99	2.91
	101.58	100.60	100.66

[1]Dana's System of Mineralogy, 1911, p. 633.

Occurrence

Phlogopite is a scarce mineral compared with muscovite, although it is quite abundant in some regions of contact metamorphism. However, so far as known, there are but few areas in the world in which commercial deposits of sheet phlogopite occur - the Provinces of Quebec and Ontario, Canada, eastern Madagascar, and Russia. In Canada the phlogopite deposits are confined to an area of about 1,200 square miles in Hull and Papineau Counties, Quebec, an approximately 900 square miles in Frontenac, Lanark, and Leeds Counties, Ontario. The location of these two areas is shown in figure 3

In Madagascar phlogopite deposits have been found in 13 of the 14 Provinces of the island. However, almost the entire commercial output is confined to the southeastern Provinces of Ambrovombe, Betroke, and Fort Dauphin, which are listed in the order of their production.

Canada and Madagascar supply the world demand for sheet phlogopite, although the U.S.S.R. occasionally exports a few tons from deposits in the Mam region and in Karelia.

In the United States a small production of sheet phlogopite was made 30 to 50 years ago from 2 localities in Morris County and 2 in Warren County, N.J. The deposits in Morris County are (1) 4 miles west of Morristown near the Mendham road and (2) 1 mile south of Mendham; the deposits in Warren County are (1) 3 1/2 miles west of Washington and 1 mile north of Broadway on the south slope of Scotts Mountain and (2) 6 miles northeast of Phillipsburg and 3 miles north of Stewartsville. These deposits did not prove extensive or rich enough to justify continued mining.

Geologists hold diverse views as to the origin of deposits of sheet phlogopite, but the author accepts the supposition of Hess[10] that they were formed by pegmatitic solutions inter-

9 Schaller, W. T., U.S. Geological Survey Report D-269 to Scott Turner, Director, U.S. Bureau of Mines, Oct. 30, 1933.
10 Hess, Frank L., Pegmatites: Econ. Geol., vol. 28, August 1933, p. 454.

jected into the easily soluble limestones, as observed petrographic relationships in all the deposits may be accounted for thus.

USES OF MICA

The peculiar physical properties of mica - its high dielectric strength, perfect cleavage, flexibility, chemical and physical stability, transparency, and luster - make it serviceable in many industries and in many diversified uses. In some of these it is indispensable, as no satisfactory substitutes have been discovered.

Mica is the most valuable dielectric known; more than 90 percent of the world production of sheet mica is now consumed by the electrical industries. It is used as insulating rings, sleeves, and bushings and commutation-segment insulation in electric motors and generators and in condensers, electric-light bulbs and sockets, X-ray apparatus, spark plugs, fuses, heating elements of flatirons, toasters, percolators, and cigar lighters, induction coils, brush-holder studs, cable-joint insulation, grid rheostats, and dozens of other electrical devices. Films of both muscovite and phlogopite only one thousandth of an inch thick commonly withstand 5,000 volts without puncture when tested with spherical electrodes; muscovite free from bubbles and stains is ideal for use in electric condensers as it shows an exceedingly low power loss. The ability of mica to withstand high temperatures and corona discharge and the fact that it is not affected by oil or water add greatly to its desirability as an electric insulator.

The use of mica in the electrical industries was greatly enhanced by the invention in 1894 of built-up mica made of thin mica films or splittings cemented by shellac. Inasmuch as built-up mica can be made in sheets (plate mica) of almost any desired size and milled to uniform thicknesses, it is more easily fabricated than natural sheet mica. Further, it can be made into tubes of circular, triangular, or complex cross-section having multiple compartments, and with suitable binders it can be hot- and cold-molded into almost any desired shape.

Glyptal and other binders in place of shellac makes a more satisfactory product for certain uses. Inorganic binders are used principally in making built-up mica for heating elements. Mica paper and mica cloth in sheet form or as tape are made by bonding one or more layers of mica splittings on or between special papers and cloths. They are used for insulation in armature slots, commutator cores, magnets, etc., and for wrapping and winding coils and armatures.

Thin films of clear muscovite are irreplaceable in the manufacture of high-grade, small-capacity condensers such as are used in radio apparatus; the maintenance of the radio industry hinges in part upon ample supplies of suitable mica for making these condensers. Mica condensers are also used in telephone and telegraph systems.

Mica is substituted for porcelain in spark plugs designed to withstand unusual thermal and mechanical shock; the use of these plugs is favored in airplane motors where conditions are exceptionally severe. It is claimed that they stand up better in high-compression motors than porcelain plugs. In making mica plugs a sheet of so-called "cigarette mica", flexible enough to be rolled to diameters of 1/4 inch without cracking, is wrapped around the metal spindle of the plug, and mica washers are forced over it and assembled under pressure with a bonding compound. The outer surface of the compacted washers is then turned in a lathe to the desired shape, and the insulated spindle is ready for assembly.

For some dielectric uses amber mica or phlogopite is preferable to muscovite, as the light-colored varieties particularly will withstand a higher temperature. Further, amber splittings produce a more easily molded built-up mica, because they are less elastic than muscovite splittings. Phlogopite is also generally preferred for insulating commutator seg-

ments, because it wears down as fast as the copper. Muscovite placed flush with the circumference of the commutator would form hard ridges owing to its superior elasticity and wearing qualities, although it is not as hard as the more friable phlogopite.

In a discussion of the electrical uses of mica it should be pointed out that although amber mica is preferable for certain uses it can be replaced in almost every instance by muscovite with but slightly decreased efficiency. For example, one of the principal demands for amber mica is for the insulation of commutator segments, yet muscovite can be used with satisfactory results for this purpose by undercutting the mica to bring it below the surface of the copper. On the other hand, phlogopite cannot displace muscovite in many uses; it cannot be employed for condenser mica on account of its high power factor or for any purpose where high transparency is necessary. Specifications for dielectric mica are discussed in a later section.

The first commercial use of mica was for glazing, and clear muscovite has been used for this purpose for centuries. Because of its transparency, noninflammability, and resistance to shock, mica was used extensively during the latter half of the nineteenth century for stove windows and chimneys and shades for open-flame lights. Since the use of stoves for househeating has declined and gas and oil have been replaced largely by electricity for lighting the use of mica for glazing has decreased considerably, although there is still a fair demand for it as windows in gasoline, oil, and coal stoves, as chimneys for gasoline lanterns, shades for candle and other open-flame lights, nonbreakable spectacles for industrial use, windows in gas masks, and for glazing in metallurgical furnaces and kilns where it is subject to high temperatures. The use of built-up mica in torchiere chimneys, lamp shades, and panels is sufficient to warrant the manufacture of special art micas for these and other decorative purposes.

In addition to its uses for insulation and glazing, mica, because of its elasticity, makes excellent diaphragms for acoustic apparatus; at one time it was used extensively for this purpose in telephones and phonographs.

Grinding mica imparts to it broader fields of usefulness, depending on whether it is wet- or dry-ground. Wet-ground mica finds its principal use in the wall-paper trade where, with suitable vehicles, it is used as a decorative ink. It also forms a highly desirable filler for rubber but in general cannot compete in this field with talc, silica, asbestos, and other cheaper fillers. Wet-ground mica, however, is employed extensively in painting the water bags used in vulcanizing automobile tires, as it prevents sticking and gives the goods an excellent finish.

Dry-ground mica is used principally in the manufacture of rolled roofings and asphalt shingles to prevent adhesion of finished surfaces and to give the material better appearance and wearing qualities. Mica is particularly suited for this use because of its flakiness which prevents its absorption by the freshly made goods and because it is unaffected by the acid in the asphalt or by weathering. Roofing mica, whether derived from scrap or mica schist or recovered as a byproduct from kaolin mining, usually is graded to pass a 10- to 20-mesh screen. Larger sizes of dry-ground mica are used extensively for Christmas-tree snow and other decorative purposes. Finely ground mica is one of the principal constituents of many plastic wall finishes, rendering them particularly receptive to textural effects. Mica is also used for surfacing stucco and concrete to impart a stone finish and in the manufacture of artificial stone.

Ground mica is an excellent thermal and sound insulator; it is surprising that it has not been used more extensively for these purposes, just as heat-treated vermiculite is employed in walls and ceilings of buildings, wall board, pipe covering, etc. Mica, however, has been used to a limited extent as a thermal insulator in the heat treatment of steel.

Finely ground mica makes an excellent lubricant and is incorporated with greases for this purpose. Bonded with lead borate, it forms an electric insulator which can be molded at dull-red heat, can be drilled and machined, and has high mechanical and dielectric strength, making it suitable for aerial insulators, bases for radio tubes, etc.

SHEET-MICA DEPOSITS OF THE UNITED STATES

Geographical Distribution of Deposits

Although mica is an extremely common mineral, occurring in all 3 of the main classes of rocks (igneous, sedimentary, and metamorphic), crystals large enough to yield sheet mica are confined to 2 rocks. As already stated, large muscovite crystals occur only in replacement pegmatites, and the less common phlogopite or amber mica is found in pyroxenic rocks. Except for a few small deposits of phlogopite in northern New Jersey and New York, there are no known deposits of this mineral in the United States. A discussion of domestic sheet-mica resources is therefore confined to muscovite deposits or muscovite-bearing pegmatites.

Figure 3 shows the principal areas in the United States that contain such pegmatites. It will be noted that the largest district extends from central Virginia through the western Carolinas, northern Georgia, and well into Alabama. This is by far the most important area and probably contains the largest reserves of commercial sheet mica. Second in importance is a relatively small region in southwestern New Hampshire, which has produced almost as much mica as the larger one just described. The larger comparative production in New Hampshire has been due to the fact that the pegmatites there are not covered to considerable depths with residual soil, as in the South, and can be examined and exploited more easily.

Next in importance as a source of sheet muscovite are the pegmatites of the Black Hills in southwest South Dakota. This area has contributed notable quantities of muscovite and has excellent possibilities for further development. A fourth area about the size of the New Hampshire district in northern New Mexico, has been developed to some extent but gives little evidence of becoming an important producer of sheet mica, as most of the muscovite from this district is "A", wedge, or tangle-sheet or so badly distorted and ruled as to make it fit only for scrap.

Small areas in southwestern Maine and central Connecticut contain a few deposits of good commercial grade. In Colorado a large area of mica-bearing pegmatites skirts the eastern slope of the Rockies and extends south from the Wyoming border to a little beyond the central part of the State. This region includes many scattered pegmatites, some of which have yielded small quantities of sheet muscovite, but as a whole the mica is of scrap quality. A small district in Latah County, northwestern Idaho, is a sporadic producer of small quantities of sheet muscovite of excellent quality, but because of distance from markets for scrap mica the development of mica mines in this area is seriously handicapped. Figure 3 shows small areas of muscovite pegmatites in Maryland, South Carolina, Texas, Wyoming, Nevada, and California; none of these States, however, has ever been an important producer of mica.

Description of Deposits, by States

Alabama

The mica-bearing pegmatites of Alabama are confined to the east central part of the State, the best deposits being in Randolph, Clay, and Tallapoosa Counties. Other deposits are in Lee and Coosa Counties. The mica-bearing area forms the southern end of the great

South Appalachian mica-pegmatite belt that extends northeast over 600 miles as far as central Virginia. The country rocks are crystalline schists, which extend northeast into Georgia and are probably the same as the Carolina gneiss farther north. The pegmatites cut the enclosing rocks at all angles and occur as lenses, sheets, and irregular masses, which in most instances have been kaolinized to a depth of 20 to 50 feet.

Colorado

Although Colorado has a large area of mica-bearing pegmatites no worth-while production of sheet mica has been made within the State. The mica is mostly A, wedge, and tangle-sheet suitable only for grinding.

Connecticut

Considerable scrap mica has been produced from time to time as a byproduct of feldspar mining in Middlesex, Hartford, New Haven, and Litchfield Counties, Conn. In general, mica from this State is A, wedge, tangle-sheet or ruled; only a few quarries have produced good sheet. Of recent years almost the entire sheet-mica output of the State has been derived from the Strickland quarry near Portland, Middlesex County.

Georgia

Mica-bearing pegmatites are found in twenty or more counties in Georgia, including Carroll, Cherokee, Elbert, Hall, Hart, Henry, Lumpkin, Meriwether, Monroe, Oconee, Paulding, Pickens, Rabun, Talbot, Troup, Union, and Upson. Most of them are in the Piedmont Plateau, but some occur in the rough mountainous section in the northeast corner of the State. As in North Carolina, the deposits are associated chiefly with Carolina and Roan gneisses, but in Pickens County a few of them are in later rocks, probably of Cambrian age. The rocks in the mica-bearing areas have been deeply weathered, and many of the pegmatites have been converted into "flukens" or decomposed pegmatitic material, the outcrops of which are marked by kaolin containing quartz boulders and clay-stained mica books scattered over the surface. Weathering often extends 50 to 75 feet beneath the surface, making it possible to mine the decomposed pegmatite with pick and shovel. Georgia mica is usually of good grade, although much of that near the surface is clay-stained. On the whole, the mica deposits of the State are virtually undeveloped, only a small amount of prospecting having been done on a few of the deposits. During the World War some of the flukens were mined to shallow depths with considerable profit. The author visited a dozen or more prospects in Cherokee and Upson Counties in which he observed good mica showings; he believes that the mica deposits of this State, under suitable market conditions, offer a promising field of development.

Maine

Most of the mica produced in Maine is obtained as a byproduct of feldspar mining from quarries in Androscoggin, Oxford, and Sagadahoc Counties in the southwestern part of the State. In the majority of the deposits the mica is fit only for scrap, but some excellent sheet has been obtained from several quarries in Oxford County, notably the Hibbs mine near Hebron and the Mt. Mica mine at Paris.

New Hampshire

The principal mica deposits of New Hampshire are in two groups in the southwestern part of the State, one of which is in southeastern Grafton County and extends into Sullivan County

and the other is in the north central part of Cheshire County. A few small, sporadic occurrences are in Merrimac, Strafford, and Coos Counties, but these are of little importance. The deposits lie in rough, mountainous country at elevations of 800 to 3,000 feet. The larger group of mines, in Grafton County, is in a region of abandoned farms and neglected roads. The rocks are metamorphic schists and gneisses intruded by granite and pegmatite. The schists and gneisses, of great age, include biotite and muscovite schists interspersed with layers rich in quartz, black tourmaline, and garnet. The country is glaciated, and the pegmatites on the steeper slopes are more exposed than similar occurrences in the Southern States, although in the valleys they may be covered to great depths with glacial gravels.

The map of southern New Hampshire (fig. 4) shows the location of 54 of the principal mica mines and prospects of the State.

As a whole, the New Hampshire mines produce a larger percentage of white mica than those of North Carolina, although excellent ruby is common. Occasionally 2 and sometimes 3 distinct types of mica are found in the same pegmatite, as, for example, at the French mine of the New Hampshire Mica Co. at Alstead, where white, ruby, and green micas occur in horizons separated only by a few feet.

Wages for mine labor in New Hampshire have been considerably higher than those paid in the South and have handicapped mica mining in the State. Most of the mica deposits also are not easily accessible, and transportation of men and supplies is both expensive and difficult. The State, however, has many mines that have made good records as producers and have not been worked out and many promising prospects; these would warrant reopening and development in the event of higher prices for their product.

New Mexico

The principal mica deposits of New Mexico are west and southwest of Petaca in Rio Arriba County and in the Glorieta Mountains in San Miguel County.

Most of the deposits in Rio Arriba County lie in broken, mountainous country at elevations of 6,500 to 8,000 feet and 8 to 15 miles west of the Denver & Rio Grande Western narrow-gage tracks between Santa Fe, N. Mex., and Alamosa, Colo. The region is semi-arid at the lower elevations, but the mountains are more abundantly watered and are forested with pine. Petaca, the nearest settlement to most of the mines, is about 9 miles by road west of Servilleta, which serves as a shipping point for most of the mica produced in the district.

Among the mines and prospects examined in this district are the Cribbenville, Globe, American, Silver Ring, Fridlund, Monta Vista, Transcript, Moon (Nos. 1 and 2), Queen, Varos, Miller and Stiles, and Alamos, all in the vicinity of Petaca, and the Meda mine of the General Mica Co. near Ojo Caliente. In general, the mica from these properties is badly ruled and distorted and contains so much A mica and tangle-sheet that it is fit only for scrap. A small percentage, however, will yield good punch and small sizes of dimension sheet. As the deposits are considerable distances from a railroad and markets, the production of scrap mica has generally proved unprofitable.

The deposits in the Glorieta Mountains in San Miguel County are identical with those of Rio Arriba County in the character of their mica.

In the writer's opinion New Mexico cannot be considered a probable source of any important quantities of sheet mica larger than punch.

North Carolina

Sterrett[11] has grouped the mica deposits of North Carolina in three main belts - the Cowee-Black Mountain, the Blue Ridge, and the Piedmont. The Cowee-Black Mountain belt lies

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11 Sterrett, Douglas B., Mica Deposits of the United States: U.S. Geol. Survey Bull. 740, 1923, 342 pp.

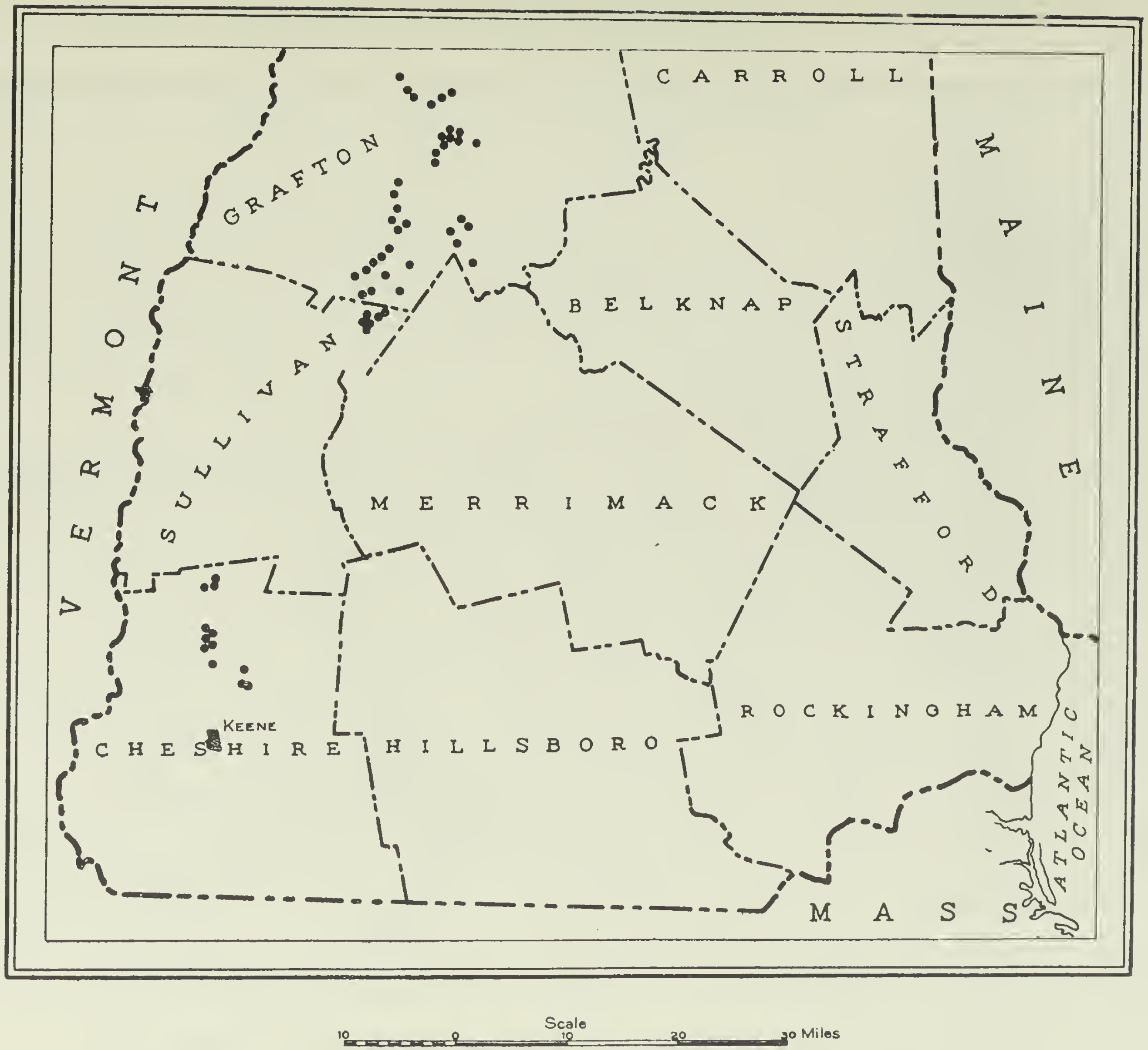

Figure 4.—Map of southern New Hampshire showing location of mica mines and prospects.

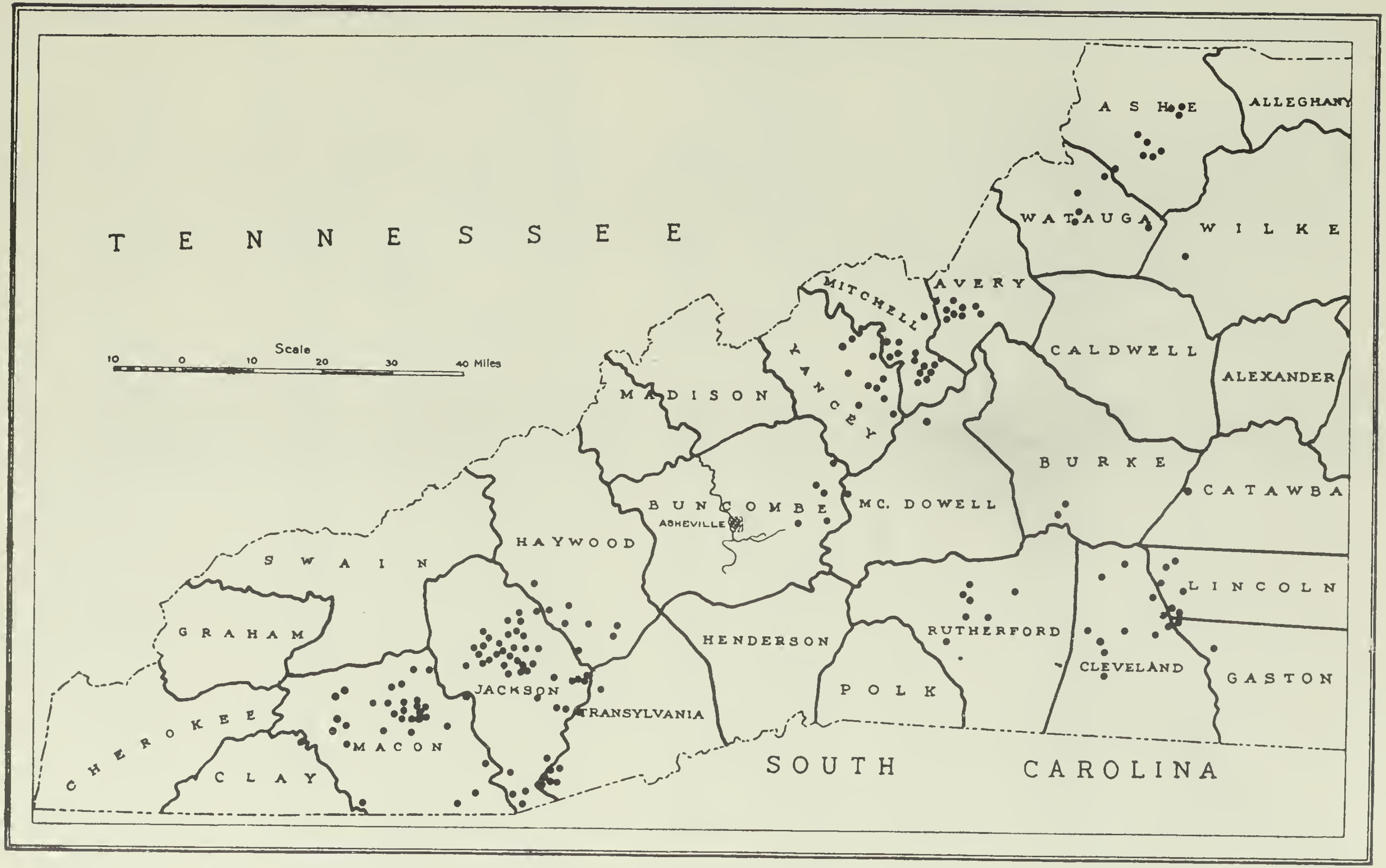

Figure 5.—Map of western North Carolina showing location of mica mines and prospects.

west of the Blue Ridge and roughly parallels the western border of the State, traversing Ashe, Watauga, Avery, Mitchell, Yancey, Buncombe, Haywood, Jackson, and Macon Counties. This is the most productive region in the State, and the mica from it is usually an excellent, clear ruby. The Blue Ridge belt follows the Blue Ridge Mountains through the State, extending on both sides of them but lying principally on their eastern slope, and embraces deposits in Jackson, Transylvania, McDowell, Mitchell, Yancey, Caldwell, and Wilkes Counties. In general, the mica from this belt is dark smoky to greenish brown and more or less specked. The Piedmont belt lies southeast of the Blue Ridge in the Piedmont Plateau and includes deposits in Burke, Cleveland, Rutherford, Gaston, Lincoln, Catawba, and Stokes Counties. The mica from this belt, particularly that mined in Cleveland, Lincoln, and Caston Counties, is clear ruby of excellent quality, similar to that of the Cowee-Black Mountain belt.

The mica mines in the first two belts are at altitudes of 2,000 to 6,000 feet in the heart of the Appalachians, some on the rugged slopes of high mountains where the pegmatites are well-exposed and others on the gentle slopes of valleys where the pegmatites may be covered to a considerable depth with residual soil. In general, the location of deposits in these two belts facilitates mine drainage, an important factor, as the ground-water level in this region is not deep and the rainfall is heavy. In the Piedmont belt the mines are at slight elevation in a flat country, so that they cannot be drained by tunnels, and pumping is necssary.

The mica-bearing pegmatites of the State occur in highly metamorphic rocks, probably all Archean, and consist largely of schists and gneisses, which have been altered greatly through extensive folding and faulting and great pressure. The principal formations in the mica regions are the Carolina and Roan gneisses interbanded and cut at all angles by pegmatites, locally mica-bearing.

Figure 5, a map of western North Carolina, shows the location of 166 mica mines and prospects.

South Dakota

The principal mica deposits of South Dakota are in the vicinity of Custer and Keystone in the southern part of the Black Hills. The mines in this region have not been worked actively for nearly 20 years; from 1907 to 1911, the years of largest production, the annual output ranged from 500,000 to 1,500,000 pounds of rough sheet mica. The mines that were operated intensively during this period are now closed, as present costs are too high to warrant production. Recent prospecting, however, has disclosed several promising deposits, and the possibilities of obtaining considerable tonnages of sheet mica from this region would be excellent if prices were higher.

The Climax, White Star, St. Louis, Crown, New York, and Mica Wonder, all within a radius of 6 miles of Custer, are among the best-known mica properties. The Peerless and Hugo feldspar mines near Keystone produce considerable quantities of mica as a byproduct, but most of it is of scrap grade.

Virginia

The principal mica production of Virginia has been derived from deposits in Amelia, Goochland, and Hanover Counties; mica mines have also been worked in Amherst, Bedford, Charlotte, Franklin, Henry, Pittsylvania, and Prince Edward Counties. All these counties are in the Piedmont southeast of the Blue Ridge. The mica-bearing pegmatites occur largely in pre-Cambrian gneisses and schists and present no unusual features except in a few deposits where the association of amazonite, clevelandite, and oligoclase with brilliant chatoyance, spessarite, topaz, phenacite, microlite, columbite, monazite, and other rare-earth minerals makes the occurrences of special interest to the mineralogist.

Much of the sheet mica from Virginia is clay-stained, as most of the mines are shallow and the rocks enclosing the pegmatites have been decomposed to considerable depths. Otherwise it is of good quality, and much of the production has been utilized as stove mica.

MINING METHODS

General Features

The mica-mining industry in all producing countries is characterized by many small operations worked with a minimum of mechanical equipment and financial investment; the irregularity of both the pegmatites and the mica inclusions tends to discourage large, systematic operations. Domestic mica mines may be divided into three groups: (1) Small mines which are generally operated spasmodically, with little or no mechanical equipment; (2) medium-size mines which have been successful in a small way and have been increased in size and equipped with some machinery; and (3) large, well-equipped mines operated according to systematic mining methods.

The first group is operated in a most elementary way. The mine workings are very irregular and follow the mica occurrence in the pegmatite along rich streaks and from one pocket to another. As little waste rock as possible is taken out because of the difficulty in removing it through the small tunnels and openings. This method of mining is called "groundhogging" or "gophering."

Considerable good sheet mica is sometimes recovered from these small mines; but, broadly, they are uneconomic as they yield only a small percentage of the mica in the deposit and leave the workings in an unfavorable condition for reopening. They may be justified, however, in that they may produce some mica at a profit and they serve to prospect the deposit with the result that it may finally be developed into a profitable mine. Most small mines are usually operated as open-pit workings and are abandoned as soon as excavation reaches water level. Where the deposits are opened by a tunnel natural drainage is of great assistance.

If small operations disclose profitable quantities of mica, mechanical equipment may be purchased, mining systematized, and air compressors, drills, and pumps installed. An incline may be driven in the pegmatite to serve as a haulageway over which cars of mica and waste are brought to the surface. Any systematic stoping is generally impossible because of the irregularity of the deposits. The mica is recovered by driving simple breast stopes where it occurs most plentifully. Certain characteristics of the mica occurrence in pegmatites are often pronounced; for example, the mica may be confined largely to zones within 6 or 8 feet of the hanging wall, or rich pockets may be found associated only with large masses of quartz. This habit of occurrence may be a valuable aid in mining. Stulls are placed in the stopes to prevent slabbing from the walls, and timbering is done where necessary to hold the roof. Some flat-lying pegmatites have been worked by room-and-pillar methods.

In the third and much the smallest class of mines operations are well-organized. The ordinary practice is to sink a vertical shaft to cut the hanging wall at depth or to sink an inclined shaft along the foot wall. Drifts are run from this shaft into the pegmatite, and the mica-bearing rock is removed by breast or overhand stoping. A good example of such a well-planned mine is the Alexandria of the General Electric Co., at Alexandria, N.H. The workings of this mine are lighted by electricity, and considerable mica has been blocked out.

In mica mining care must be taken not to drill through or place powder charges in rich pockets of mica crystals; these pockets should be removed as far as possible by mining around them. An experienced drillman can readily detect mica under the drill by its peculiar resilience. Forty percent dynamite is commonly used. After a round of shots has been fired and the powder fumes cleared the mica is hand-picked from the muck and bagged before it is hoisted to the surface. If feldspar is recovered as a byproduct, all the muck may be hoisted to the surface, where the feldspar and any good mica overlooked underground is sorted out.

Considerable mica is recovered as a byproduct from feldspar mining. Most feldspar mines are usually worked as opencut quarries, although there are a few large underground operations Some feldspar mines are splendidly equipped; one loads all broken rock with a gasoline shovel, crushes to size, and runs it over a picking belt, the waste being stacked mechanically. In these feldspar operations any mica recovered is thrown to one side and later sorted into block mica and scrap.

On the whole, mica mining, particularly if conducted by inexperienced operators, is a great financial risk; on account of the irregularity of the pegmatites and of the enclosed mica occurrences, rarely is a large-scale operation justified.

Summary of Production and Cost Data at Two Mines in North Carolina

Tables 3 to 8, inclusive, summarize the production and cost data at two mica properties in North Carolina. Details of the operations have been presented in an earlier circular.[12]

TABLE 3.- Analysis of mining operations

Rock and spar mined and hoisted	tons	13,655
Rock mined and back-filled	do.	800
Total rock and spar mined	do.	14,455
Shots fired		5,113
Holes drilled, total length	feet	25,565
Per ton of rock broken	do.	1.75
Dynamite used (40 percent)	pounds	9,932
Average charge per hole	do.	1.94
Rock broken per pound of dynamite	tons	1.4
Block mica recovered (not including mine scrap)	do.	276
Recovered per ton of rock	pounds	38

TABLE 4.- Analysis of production

CLEAR MICA			
Size, inches	Pounds	Total value	Value per pound
8 by 10	100		
6 by 8	189		
4 by 6	690		
3 by 5	880		
3 by 4	659		
3 by 3	799		
2 by 3	1,886		
2 by 2	1,120		
1 1/2 by 2	1,068		
Total clear mica	7,391	$10,077.31	$1.35

12 Urban, H. M., Mica - Mining Methods, Costs, and Recoveries at No. 10 and No. 21 Mines of the Spruce Pine Mica Co., Spruce Pine, N.C.: Inf. Circ. 6616, Bureau of Mines, 1932, 16 pp.

TABLE 4.- Analysis of production - Continued

ELECTRICAL MICA			
Size, inches	Pounds	Total value	Value per pound
8 by 10	373	...	...
6 by 8	941	...	...
4 by 6	3,577	...	...
3 by 5	3,888	...	...
3 by 4	2,721	...	...
2 by 3	5,602	...	...
2 by 2	14,285	...	...
Total electrical mica	33,681	$28,588.30	$0.85
Total sheet mica	41,072	38,665.61	0.94
Punch mica	156,238	7,761.85	.05
Factory scrap mica	354,776	3,547.76	.01
Total block mica	552,086	49,975.22	0.0905
Value of mine scrap mica and feldspar	...	6,987.14	...
Total value recovered	...	56,762.32	...

TABLE 5.- Costs

	Total	Per ton of rock mined	Per pound of block mica recovered
Mining labor	$24,455.34	$1.692	$0.0443
Mining supplies, including fuel	9,455.87	.654	.0171
Sheeting costs	5,854.81	.405	.0106
Total cost of mining and sheeting	39,766.02	2.751	0.0720

TABLE 6.- Analysis of mining operations

Rock mined and hoisted	tons	4,530
Holes drilled, total length	feet	9,290
Per ton of rock broken	do.	2.05
Shots fired		2,066
Dynamite used (40 percent)	pounds	3,814
Average charge per hole	do.	1.84
Rock broken per pound of dynamite	tons	1.2
Block mica recovered	do.	107
Recovered per ton of rock	pounds	47

TABLE 7.- Analysis of production

Size, inches	Pounds	Total value	Value per pound
CLEAR MICA			
4 by 6	18		
3 by 5	95		
3 by 4	137		
3 by 3	343		
2 by 3	1,702		
2 by 2	1,641		
1 1/2 by 2	8,946		
Total clear mica	12,882	$5,391.60	$0.42
ELECTRICAL MICA			
3 by 5	6		
3 by 4	12		
3 by 3	27		
2 by 3	185		
2 by 2	447		
Total electrical mica	677	$251.80	$0.365
Total sheet mica	13,559	5,643.40	0.417
Punch mica	106,849	5,344.95	.05
Scrap mica	93,833	562.99	.006
Total block mica	214,241	11,551.34	0.0539

TABLE 8.- Costs

	Total	Per ton of rock mined	Per pound of block mica recovered
Mining labor	$6,519.07	$1.439	$0.0304
Mining supplies (including fuel)	1,673.05	.369	.0078
Sheeting costs	1,922.90	.424	.0090
Total cost of mining	$10,115.02	$2.232	$0.0472

Many interesting facts are revealed by comparative analysis of tables 3 and 6, which give production data for Nos. 10 and 21 mines, respectively.

By dividing the total value of the block mica recovered at the No. 10 mine by the tons of rock broken the value of the rock for mica alone is found to be $3.46 per ton. If the byproducts feldspar and mine scrap mica are included, the recoverable value of the rock is $3.93 per ton.

At No. 21 mine where there is no merchantable feldspar or mine scrap mica the recoverable value in the rock was $2.55 per ton. These values show that even when a pegmatite proves rich or at least rich enough to be worked at a profit the value per ton of rock considered as ore is low.

A similar analysis of tables 5 and 8 shows that the mining cost (labor and supplies per ton of rock was $2.35 and $1.81, respectively, at Nos. 10 and 21 mines; these figures when added to the sheeting costs give $2.75 and $2.23 per ton as the cost of mining and sheeting the block mica recovered.

The mining costs given above are high and plainly indicate the need of more efficient mining methods. It must be remembered, however, that there seems to be no way to prove mica values in advance of mining and that the initial investment required for the installation of machinery for low operating cost is not warranted except in unusual instances. Investment in more efficient equipment might be justified if a group of mines were operated which could be worked out one after the other and if each individual pegmatite were mined rapidly.

It will be noted that there is a great difference in both the size and quality of the mica produced by the two mines. At No. 10 mine 18 percent of the sheet mica was clear and 82 percent was electrical or stained mica. At No. 21 mine 95 percent was clear and only 5 percent was of electrical grade. At No. 10 mine 24 percent of the sheet mica was in the 3 by 5 inch class or larger, whereas at No. 21 mine less than 1 percent was in these larger classes. Finally, the average value of the block mica, in sheeted or prepared form, was $181 per ton at No. 10 mine, whereas at No. 21 mine it was $108 per ton.

The wide differences in production costs, yields, and the grades and classifications of mica recovered at these two mines are characteristic of mica mining the world over.

PREPARATION OF SHEET MICA FOR MARKET

Physical Characteristics of Book Mica

General Features

Mica as it comes from the mine is commonly in rough blocks ranging from a few inches to as much as 2 or 3 feet in maximum diameter. These blocks usually have ragged outlines and no plane boundaries, although they occasionally show well-developed crystal faces of hexangonal or rhombic prisms. Due to structural characteristics, inclusions, and color the rough crystals or books have certain physical peculiarities, to which miners and mica dealers apply descriptive terms. Thus, micas are usually characterized by their various structural imperfections as "ruled", "ribboned", "A", "hair-lined", "herringbone", "fishbone", "horsetail", "feather", "wedge", and "tangle-sheet." Inclusions have given rise to such terms as "black-spotted", "heavy-stained", "red-stained", "clay-stained", etc., while different-colored micas are variously known as "rum", "ruby", "white", "smoky", "green", "light amber", "silver-black", etc.

Structural Imperfections

The structural imperfections of rough mica crystals constitute the largest factor in determining the yield of sheet mica.

Parting planes often develop in the mica books from strains or movements in the enclosing rock, splitting the mica sheets into narrow strips or ribbons. This ruling is sometimes so extensive that the ribbons are almost hairlike and may render large mica crystals, otherwise of excellent quality, fit only for scrap.

In A mica two series of striations cross the sheets at an angle of about 60° with each other, forming a V. The third striation necessary to form the letter A is lacking, but this variety is nevertheless termed "A" mica. Sometimes the striations are evidently caused by wedge structure in the crystals and again by small ridges or folds in the sheets. If the

striations are formed by wedging only that portion between the A lines is usable as sheet mica, but if they are caused by folding the mica may split across the folds and yield sheets of some value though not of first quality. Where the striations extend only in one direction the mica is known as "hair-line" mica.

Striations apparently identical with those of A mica but making angles of about 120° with each other and joining at a center line or spine give rise to a structure known as "fishbone", "herringbone", "horsetail", or "feather"; mica with such structure has no value other than for grinding.

The crystals of wedge mica, as the name implies, are wedge-shaped and are thicker on one side than on the other. This structure is common in A and fishbone mica and is due to unequal development in the width of the laminae forming the crystals, some extending the entire width of the block. The angle of the wedge may be as much as 30°.

"Tangle-sheet" is caused by the intergrowth of individual laminae, so that they split in some places but bind and tear in others; apparently sound crystals are thus made nearly valueless.

The mica books may be badly distorted, buckled, or corrugated, conditions probably produced by earth movements coincident with or subsequent to their crystallization. In fact, perfectly flat mica is rare; a slight waviness may be detected in even the better grades by touch or by visible differences in the reflection of light from their surfaces.

Impurities

The most common impurities in mica are oxides of iron, silica, and clay impregnating the crystals along their cleavage planes. The opportunity for the infiltration of these impurities was probably afforded by the opening of the cleavage planes through bending or distortion of the crystal by earth movements after their formation. Magnetite, perhaps the most prevalent inclusion, occurs as black and dark-brown spots and dendritic forms sometimes arranged in patterns having a definite relation to the crystal structure and again scattered irregularly through the sheets. The dark-brown color of many of these magnetite inclusions is due to the translucence of the mineral in thin films, but that the inclusions are magnetite can be proved by cutting them out and testing them with a magnet. Magnetite inclusions often alter to hematite or limonite, becoming red or brownish yellow. Striking color patterns are sometimes produced in this way; such micas are occasionally used for making lamp shades and other art objects.

In some localities thin sheets of silica are commonly found as inclusions between the mica laminae and interfere greatly with the sheeting of the mica. Some of these inclusions are heavy and occur in the form of wedges or lenses as much as a quarter of an inch thick.

Clay-staining is also a common impurity in mica and is due to the infiltration of muddy water between the laminae. It occurs only in mica coming from the zone of surface weathering and, of course, is most marked near the surface; it does not extend to the solid unweathered pegmatite. This impurity is often confined to certain planes in a crystal and may be removed by splitting.

Staining of any type renders mica unfit for use in electrical condensers, as it causes the mica to heat under an electric load. In most instances, however, the dielectric strength of mica moderately stained with metallic oxides does not appear to be lowered appreciably. Hence it is entirely satisfactory for most dielectric uses.

Crystals of garnet and black tourmaline are common inclusions in mica. Although usually small, garnets up to three quarters of an inch in diameter and tourmaline crystals several inches long have been found embedded in the sheets. Crystals of biotite also are prevalent in the muscovite, or vice versa, the two minerals generally having a common basal cleavage.

Such intergrowths, although interesting from the standpoint of the mineralogist, render the mica unfit for sheeting.

Color

The nomenclature describing the color of mica needs no explanation; sheets at least 1/16 inch or more in thickness are best for judging color, because thinner sheets are usually almost colorless. Dark mica is not as desirable as light, because it must be split thinner to give the transparency requisite for many purposes; moreover it is usually a poorer dielectric. Zonal variation in coloring usually disappears when the mica is split into thin films.

Bubbles

Mica for use in electrical condensers must be free from inclusions of air; air bubbles between the laminae are not unusual. If these are large and confined only to certain planes within the block they can be removed by splitting; in some instances, however, small bubbles are widely distributed between the folia, so that their removal is impossible. Sometimes these bubbles are microscopic and are so numerous as to form clouds in the mica. As already stated, mica containing bubbles is unsuited for use in condensers, but its dielectric strength does not appear to be adversely affected. Bubbles are probably caused by strains in the mica while in the ground, but many of them are certainly caused by rough handling in mining or in the course of preparing the mica for market.

General Features

The preparation of mica for market is necessarily a hand operation, as it requires the exercise of judgment to trim, split, cut, and properly grade mica. With the exception of the development of mechanical methods for producing mica splittings, which will be discussed later, it is probable that hand methods will be employed in the preparation of mica for an indefinite period and that labor will continue to be a most important element of cost.

All of the many forms in which completely manufactured mica is used are derived from two main classes of raw material - sheet and scrap. The preliminary preparation of mica for market consists primarily of separating it into these two classes.

Mica houses or trimming sheds, where the mica is stored and prepared for market, are provided at most of the larger mines. Generally, however, the small producers and many feldspar miners who recover mica as a byproduct sell their output either as it comes from the mine or roughly graded to firms who prepare it for the trade.

Cobbing and Rough Sorting

The rough crystals of mica as taken from the mine are of various shapes and sizes and are commonly referred to as "mine-run", "book", or "block" mica. This last term is unfortunate as it also applies to imported sheet mica. Mine-run mica is dirty and ordinarily has considerable rock adhering to it. The rough books are first cobbed, that is, all adhering rock is broken off with small hand hammers; the books are then rapped sharply to remove loose dirt. If the mica is exceptionally dirty it is sometimes passed over coarse screens. During the cobbing process the rough mica is examined carefully, and all books that are obviously so defective that they will yield no sheet mica are thrown into the scrap pile. In this way much badly ruled, fishbone, distorted, and otherwise defective mica is sorted out and requires no further handling.

Rifting

Cobbed mica is split into sheets about 1/16 inch thick or less by men and women known as "rifters." A knife having a stout, double-edged, 3-inch blade with a V-point is generally used in rifting; the edges of "tight" books are sometimes pounded with light hammers to loosen the laminae so that the rifting knife may be inserted. Considerable judgment and skill are required to split the blocks to the best advantage, that is, so that the imperfections will be removed as far as practicable and the maximum yield of high-grade mica obtained. Consequently, only thoroughly experienced rifters are employed. The products of the rifting operation are sheet stock, which goes to the trimmers, and punch or washer stock, which is commonly left with rough edges and is used for making disks, washers, and other punched forms and scrap.

Trimming

After the rifting process the ragged edges of the mica sheets are trimmed to remove the tangled ends of the laminae and thus facilitate further splitting. Trimmed sheet is known as "block", "uncut", or "unmanufactured" mica and is graded according to size and quality. Trimming may be done in a number of ways, but in general it is best accomplished with a sharp, thin-bladed knife held at a small angle with the cleavage of the sheet, so that a beveled-edged cut is produced. The beveled edge aids materially in further splitting, as the edges of each lamina project slightly beyond those of the one adjoining it, thus freeing them from entanglement. The bevel also presents a broader surface to the point of the splitting knife than a cut perpendicular to the cleavage and assists the splitter in gaging the relative thickness of the sheets to be split. Mica should always be bevel-trimmed in this way where further splitting is contemplated.

In India most mica, particularly that marketed through Calcutta, is bevel-trimmed with sickle-shaped knives and is known as "sickle-trimmed" or "India-trimmed." Sickle-trimmed mica is very irregular in shape and often has reentrant angles, but its preparation is generally excellent, all flaws and cracks being cut out. In this respect it is far superior to the usual run of domestic knife-trimmed mica, in which many imperfections often are allowed to remain. Because of its careful preparation Indian sickle-trimmed mica has won an enviable reputation in the trade and has given rise to the term "close-trimmed", in contradistinction to "rough-trimmed", from which only part of the imperfections have been removed. Mica from Madagascar, Guatemala, Argentina, and Brazil usually is sickle-trimmed. Another type of Calcutta trimming, known as "knife-trimmed", yields sheets with straight unbeveled edges in the shape of irregular polygons. Most African mica is trimmed in this way, although some is sickle-trimmed.

Mica from the Madras district in India is cut with shears into rough rectangles and is known as "Madras-cut" or "shear-trimmed" mica. The edges are not beveled but are cut normal to the cleavage. "Thumb-trimming" consists simply in breaking off with the fingers as much of the inferior material around the edges of the sheet as possible. It really accomplishes little but may be warranted in certain instances, particularly where the block mica is manufactured by the producer, as it saves the expense of more careful trimming.

In trimming mica domestic producers should bear in mind that sickle-trimming yields less waste and a larger weight of block than any other method. On the other hand, most mica cutters prefer the rectangular or Madras trimming; by purchasing the proper sizes they can predetermine waste with accuracy and can reduce it to the minimum. Trimming, of course, produces a large percentage of scrap mica.

GRADES

No other mineral product is so difficult to classify as mica or approaches it in the multiplicity of grades for size and quality, which vary widely with the country in which the mica is produced.

Domestic sheet muscovite is divided into three principal classes according to quality: (1) Clear, (2) slightly stained or spotted, and (3) heavily stained or spotted. The domestic classification with respect to size is as follows: The smallest size, designated as punch, must be large enough to yield a circle 1 1/2 inches in diameter if stained and 1 1/4 inches if clear. The next size is circle mica which yields disks up to 2 inches in diameter. Then follow the rectangular sizes: 1 1/2 by 2, 2 by 2, 2 by 3, 3 by 3, 3 by 4, 3 by 5, 4 by 6, 6 by 6, 6 by 8, 8 by 10 inches, and larger. Each size includes mica of the designated dimensions and all larger sizes to the next class. Thus, a sheet that would cut a rectangle 4 1/2 by 7 inches would be classed as 4 by 6.

Muscovite for glazing purposes, commonly known as stove mica, is classified according to quality as No. 1 stove or No. 2 stove. No. 1 stove must be clear and free from cracks and stains but may contain bubbles, whereas No. 2 stove may be spotted and stained to a limited extent.

Indian grading for size is based upon the area of usable mica corresponding to the areas shown in figure 6[13]; the general adoption of this chart for grading sheet mica and splittings is advocated by the American Society for Testing Materials.

In using the chart the mica to be graded is laid upon it with one corner at O and the maximum and minimum dimensions of the specimen extending along the lines OA and OB, respectively. The position of the mica is then shifted until its area completely covers the largest rectangle determined by a diagonal extending from O to or beyond one of the curves of the chart. The curve at the greatest distance from O, cut by the diagonal of the largest rectangular area in the mica, determines its grade number.

There are three sizes larger than those shown on the chart, which are known as special (48 to 60 square inches), extra special (60 to 80 square inches), and extra extra special (80 square inches or over). A small size, known as No. 7, having an area of less than 1 square inch has recently appeared on the market but is not generally recognized in the trade. For sizes larger than No. 4 the exact dimensions of the maximum rectangle are usually given, as a piece of mica covering 23 square inches is worth considerably more than one covering only 15 square inches, although they would both be classed as No. 2.

The following table shows the area of usable mica in the rectangles that can be cut from each of the various sizes of the Indian grading and the approximate corresponding sizes of the United States classification:

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13 American Society for Testing Materials, Tentative Method D351-33T.

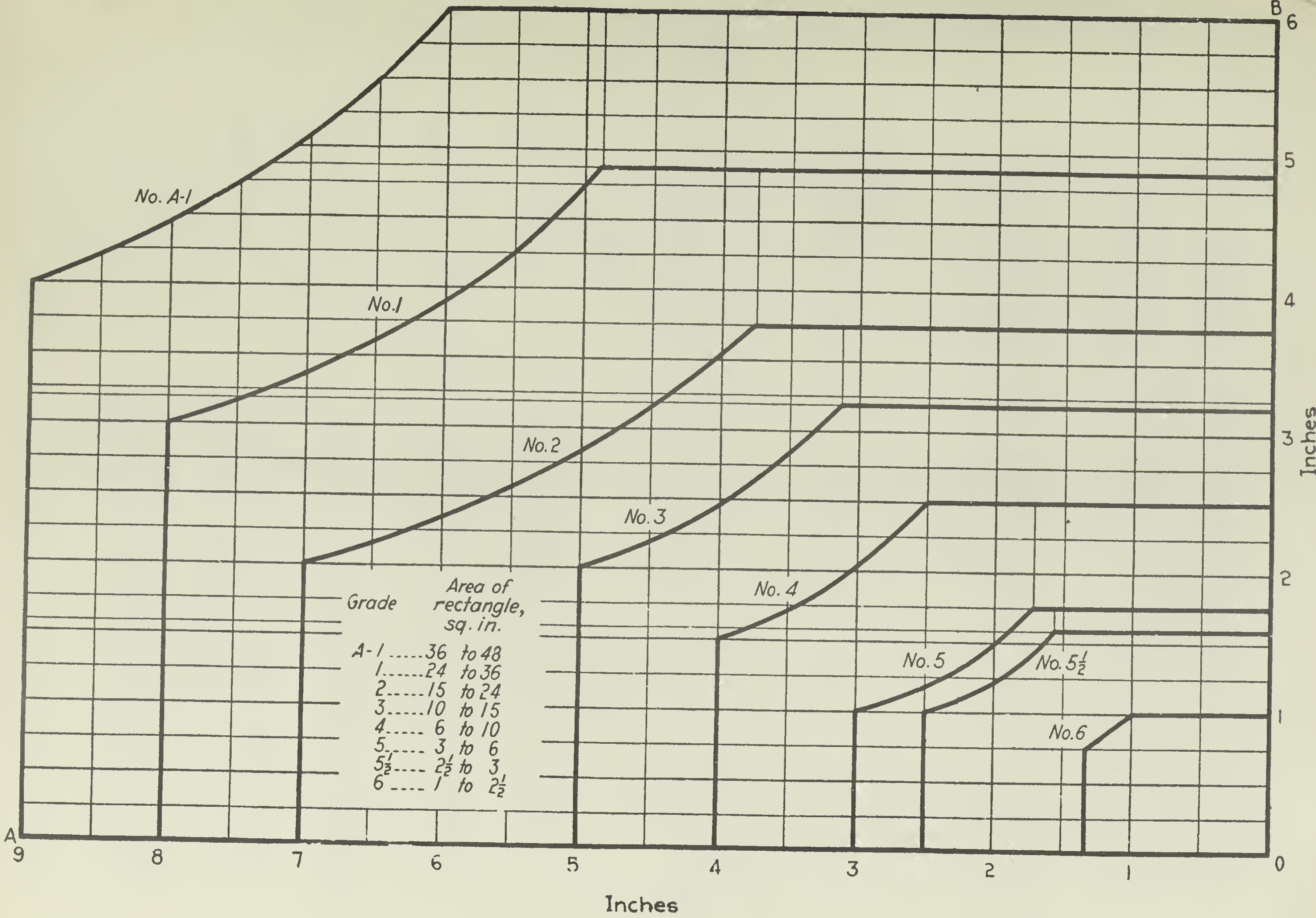

Figure 6.—Chart for India grading of mica.

Comparison of Indian and United States gradings for size

India grading	Area of usable mica based on rectangular sizes, square inches	Approximate corresponding sizes in United States classification, inches
6	1 to 2½	Punch
5½	2½ to 3	1½ by 2
5	3 to 6	2 by 2
4	6 to 10	(2 by 3 (3 by 3
3	10 to 15	3 by 4
2	15 to 24	3 by 5
1	24 to 36	4 by 6
A-1	36 to 48	5 by 8
Special	48 to 60	6 by 8
Extra special	60 to 80	8 by 8
Extra extra special	80 and over	8 by 10

Indian grading for quality comprises the nine following classes in descending order of value: 1, clear; 2, clear and slightly stained; 3, fair-stained; 4, good-stained; 5, stained; 6, heavy-stained; 7, black-spotted; 8, black-stained; and 9, badly stained. The American Society for Testing Materials in attempting to standardize grading for quality has combined the four poorer grades listed above and adopted the grading described herewith.

Quality	Description
Clear	Free of all mineral and vegetable inclusions, stains, air inclusions, waves or buckles. Hard transparent sheets.
Clear and slightly stained	Free of all mineral and vegetable inclusions, cracks, waves, and buckles but may contain slight stains and air inclusions.
Fair-stained	Free of mineral and vegetable inclusions and cracks, hard, and contains slight air inclusions and is slightly wavy.
Good-stained	Free of mineral inclusions and cracks but contains air inclusions, some vegetable inclusions, and may be somewhat wavy.
Stained	Free of mineral inclusions and cracks but may contain considerable clay and vegetable stains and may be more wavy and softer than the better qualities.
Black-stained or spotted	Same as stained but contains mineral inclusions.

The exact grading of mica for quality is extremely difficult, because it depends entirely upon personal interpretation of standards. As an aid to more uniform grading the American Society for Testing Materials proposes to prepare a set of master standards according to the above description from which photographs or transparent autochrome plates can be furnished.

Muscovite splittings are graded for size according to the Indian system, but the method of packing the splittings and their quality are also factors in determining grade. The usual grades recognized in the trade are: No. 6, cheap loose-packed; No. 6, medium loose-packed; No. 6, ordinary loose-packed; No. 6, second quality, loose-packed; No. 6, first quality, loose-packed; No. 5, special quality, loose-packed; No. 6, second quality, pan-packed; No. 6, first quality, pan-packed; No. 5, second quality, pan-packed; No. 5, first quality, pan-packed; No. 4 1/2, pan-packed; No. 6, book-packed; No. 5, second quality, book-packed; No. 5, first quality, book-packed; and No. 4 1/2, book-packed. Sizes larger than No. 4 are rare. In book-packing all splittings from one block are kept together in a book like a deck of cards. The individual splittings in the book are dusted with powdered mica to prevent them from sticking; in this form they are ideal for laying in the manufacture of plate or built-up mica. In pan-packing the splittings are laid radially in a circular pan usually 7 to 9 inches in diameter, depending on the size of the splittings, to form a thin, fairly coherent layer that can be used as a unit in the manufacture of mica plate. The grades of splittings vary widely and overlap. Hence they are usually sold under such trade names as "Walrus", "Rabbit", etc., the quality of common brands being fairly uniform and well known to mica buyers and consumers.

Sheet phlogopite or amber mica of Canadian origin is classified for size on the basis of its maximum rectangular dimensions, but the sizes differ from the United States standards. They are as follows: 2 by 3, 2 by 4, 3 by 5, 4 by 6, 5 by 8 inches, and larger. These sizes are either thumb- or knife-trimmed and are graded for quality as No. 1 (silver amber) and No. 2 (dark amber). Canadian amber splittings are graded for size as 1 by 1 undersize, 1 by 1, 1 by 2, and 1 by 3 inches and for quality, according to color.

Madagascan mica, whether muscovite or phlogopite, is graded according to the following classification, which is enforced by the local bureau of mines.

Madagascan system of grading mica for size

Series	Grade	Size of rectangle, square inches
1..........	00..	Over 48
1..........	0..	36 to 48
1..........	1..	24 to 36
2..........	2..	15 to 24
2..........	3..	10 to 15
2..........	4..	6 to 10
3..........	5..	3 to 6
3..........	6..	1 to 3
3..........	All splittings.	
4..........	Smaller sheet than grade 6.	
4..........	Scrap and ground mica.	

Amber mica is graded for quality according to its hardness; this classification is easily made, as hardness conforms closely to color. Silver amber is graded as soft; brown amber, as medium; and amber-black to silver-black, as hard. Only the soft and medium amber micas are made into splittings, which at present are confined to No. 5 and No. 6 grades.

Madagascan muscovite is loosely graded for quality into clear and stained mica.

When it is remembered that in addition to the gradings already described a dozen other countries contribute mica to the world's supply and that none of them prepares or grades mica similarly, the great desirability of universal standards for grading becomes apparent. The adoption of such standards would temporarily inconvenience producers, brokers, and consumers but would be of great ultimate benefit to the mica industry.

SPECIFICATIONS

The specifications on which mica is purchased naturally vary according to its use. For electrical purposes the dielectric strength, power factor, resistance to heat, and sometimes flexibility are important properties. Specifications for dielectric strength differ widely for different electrical uses and with different consumers, but all mica free from cracks, pinholes, and certain types of staining has such a high dielectric strength that it rarely fails from electric puncture. Some types of staining seem to have little effect on the dielectric strength; in recent tests by the Bureau of Standards the dielectric strength of some stained micas in thicknesses of 5 mils and over was superior to that of perfectly clear micas. According to these same tests, which are discussed in detail in a later section of this report, bubbles in mica do not appear to affect its dielectric strength materially. A good dielectric mica, either stained or unstained, should withstand at least 1,000 volts per mil in thicknesses of 4 to 6 mils when tested with 2-inch plate electrodes.

Mica for use in electrical condensers should have a low power factor; otherwise it will heat excessively under an electric load. Hence, stained micas or those containing bubbles should not be employed for this purpose. A satisfactory condenser mica should have a power factor of 0.02 percent or less.

All good electrical muscovite is sufficiently resistant to heat for ordinary electrical uses and will withstand 500° to 600° C. without appreciable change. Therefore no specification for heat resistance is usually required if the mica is not to be subjected to higher temperatures. A soft, light-colored phlogopite, however, should be specified for use above 600° C., as these grades of phlogopite are more resistant to heat than muscovite. Phlogopite is generally specified for use in commutators because it wears at the same rate as the copper segments, thereby keeping the surface of the commutator smooth.

Flexibility is sometimes an important property of electrical mica; for example, a flexible mica is required in wrapping the spindles of spark plugs where thin sheets have to be rolled to small diameters. A usual specification for so-called "cigarette" mica is that a sheet 1 mil thick can be rolled into a cylinder 1/4 inch in diameter without cracking.

Consumers often specify India mica partly because of the erroneous belief that India mica is of superior quality and partly because of the poor preparation of domestic mica which otherwise is in every way comparable to the Indian product.

MACHINE-SPLITTING OF MICA

The preparation of mica splittings by hand is slow and expensive, and the labor involved is the principal item of the total cost. If splittings could be produced in quantity by machine, great savings obviously could be effected. Several companies in this country have experimented recently with various processes of machine-splitting; one produced considerable quantities of amber splittings. The principle employed in this particular instance is simple - the mica books are bent to make the folia slip on each other. The mica, preferably in books less than 4 square inches in area and 3/32 inch thick, is first heated to 300° to 400° C. and then suddenly cooled in water. This treatment tends to loosen the individual laminae.

The mica from the cooling vats is placed in coarse-mesh bags, and most of the water is extracted by ordinary centrifugal dryers. The remaining water is removed in drying ovens. The mica is then ready for the splitting machine, which consists primarily of two superimposed belts moving in the same direction in contact with each other. The mica is fed between these two belts, which carry it over a roller and then alternately under and over a series of stationary rods with faces that present increasingly sharp angles. This process bends the mica books back and forth through greater and greater angles until they are finally bent through almost 90°. In this way the individual sheets of a mica book are forced to slide on each other exactly like the leaves of a magazine when bent.

This treatment bends the mica books three times in opposite directions; the conveyor belt then discharges them into the boot of an elevator, which carries them to a trommel having a screen of about 1/2-inch mesh. The trommel separates the loosened books into individual leaves or splittings and at the same time removes all fine mica as undersize. The oversize, consisting of pieces ranging from those well split to those unsplit, drops from the end of the trommel for about 10 feet and passes in front of a perforated suction roller over which runs a coarse-mesh wire belt. The suction in the roller is so regulated that the lighter well-split mica is deflected in its fall and sucked against the wire belt, while the heavier, less completely separated pieces pass by and are returned to the splitting belts for further treatment. This method of sorting the well-split and poorly split mica is surprisingly efficient. Simultaneously with the sorting, the suction roller and wire belt also act as a laying machine which spreads the mica evenly, ready for spraying with binder.

The author saw this process in operation, and although it was not perfected it worked with some degree of success. Three persons handled the entire process - one fed the mica heater, one attended to the drying, and one operated the splitting machine. The labor cost of producing splittings probably did not exceed 1 cent a pound; it is evident that the cost of this process, including overhead, is much less than that of hand-splitting. The waste was about 50 percent when amber mica recovered from old mine dumps was treated. Some weathered Canadian phlogopites can unquestionably be split successfully by the process described, but apparently it cannot handle freshly mined phlogopite or muscovite.

For several years small quantities of muscovite splittings have been made regularly by machine, but as production has not increased it appears that such methods enjoy no advantages as to cost over the hand method of splitting. However, machine-made splittings in general are reported to be more uniform in thickness than all but the best grades of the hand-made product and make superior grades of built-up mica.

It is hoped that continued efforts to develop economical processes for machine-splitting will be successful in order to relieve the domestic industry from its almost absolute dependence on imported splittings. In this connection it should be pointed out that machines can split only the same grades of mica that can be split by hand and that they cannot make splittings of tangle-sheet or other scrap micas.

MICA GRINDING

Mica is ground by either wet or dry processes, depending on the uses for which it is intended and on its physical character.

Wet-ground mica is employed principally in the wall-paper and rubber industries where a high luster and ability to mix smoothly with liquid vehicles are required. Wet-grinding under carefully regulated conditions is the only process known for reducing mica to fine sizes without destroying its sheen and slip. Freedom from biotite, heavy staining with clay or iron oxides, and excessive quantities of gritty minerals is a requisite for wet-ground mica for the wall-paper trade. Color is also important, as some micas do not produce as white a product as others. If wet-ground mica is intended for the rubber trade color and

freedom from dark specks is generally unimportant; wet-ground biotite and chlorite are sometimes sold to this industry. Wet-ground mica should have a high metallic luster, should feel slippery and be free from grit, and should mix smoothly with liquid vehicles.

The following screen analyses show the fineness of two standard brands of wet-ground mica for use in decorating wall paper. The weight per cubic foot of the ground mica is also given.

Screen analyses of wet-ground mica

Through	Brand 1, percent	Brand 2, percent
60-mesh	100	100
80-mesh	99.5	99.9
100-mesh	99.0	99.7
150-mesh	98.2	97.5
200-mesh	97.2	94.0
325-mesh	87.7	76.3
Weight per cubic foot, pounds	14	15.5

Dry-grinding processes subject the mica to such violent abrasion that the edges of the individual particles are torn and hackly; in fine sizes (under 40-mesh) the smooth surfaces of the flakes are largely if not entirely destroyed. Mica ground dry to 100-mesh size looks like flour, has but little slip, and is difficult to incorporate in smooth mixtures with liquids. This property of not mixing well with liquids gives the pleasing textural effects obtained with wall finishes containing a high percentage of dry-ground mica ranging in size from 70- to 220-mesh.

Dry-ground mica is used chiefly to prevent adhesion between surfaces of asphalt shingles and rolled roofing and to impart wearing qualities and a pleasing finish to these products. For this purpose 10- to 40-mesh size weighing 14 to 20 pounds per cubic foot is usually specified. A light-weight mica is desired by the roofing trade, as it has a greater covering power per unit of weight than a heavier product. However, in an effort to obtain large coverage the appearance of the articles is sometimes sacrificed, as the flakes of an unusually light mica are so thin that the dark background of the material is too readily seen through them. Consequently they do not produce as bright and pleasing a finish as thicker and heavier flakes. Coarser sizes of dry-ground mica (4- to 10-mesh) are used for Christmas-tree snow and similar decorative purposes, but the consumption of these sizes is comparatively small.

Wet-Grinding

Wet-grinding is done in chaser mills consisting of annular steel or wooden pans up to 10 feet in diameter and 40 inches in depth, in which wooden rollers rotating on horizontal arms revolve about a central shaft. The bottoms of the pans are lined with and the rollers made of end-grain wooden blocks, oak, maple, and black gum being preferred. The mills may be equipped with 2, 3, or 4 rollers ranging in diameter from 30 to 40 inches. The roller faces are generally 20 to 24 inches wide, and the rollers are so arranged that they can be raised or lowered according to the depth of charge in the mill. Steel plows following each roller turn the charge to present new material to the grinding action of the succeeding roller and keep the mica in the path of the rollers. The mills usually operate at 20 to 40 r.p.m., varying with the dimensions of the mill and the weight of the charge, and consume

about 20 hp. Complete grinding of 1-ton charge of mica requires 4 to 8 hours; the time varies with the physical character of the mica and speed of the mill. The mica, unless it is clean shop scrap, is washed thoroughly to remove fine rock and dirt before it is ground. Grinding is started without water, but as the mica breaks up water is added gradually to form a stiff paste and the grinding is continued under carefully regulated conditions until the charge is completely ground. The friction generated in the charge produces so much heat that the water actually boils, and care must be taken to prevent the mica from becoming too dry and "burning." The water content of the charge must therefore be watched carefully. If too much water is used proper grinding is precluded, and if too little is used the mica will burn and lose its sheen.

The ground charge is sluiced from the mill into wooden sand boxes or launders, where the gritty impurities and coarse mica settle. The overflow carries the fine mica to wooden vats, where it is allowed to settle and the clear water is siphoned off. The mica sludge is then transferred direct to steam tables, or it may be filtered-pressed before drying. The dried mica is run over a vibrating scalping screen, usually of about 60- or 80-mesh, to remove heavy particles that would injure the fine silk cloths of the bolting machines on which it is sized. The bolting machines are similar to those employed in bolting flour; replacement of the expensive silk cloths is a large item in the cost of screening mica. The mica is bolted through 160- to 300-mesh cloths according to specifications, and the oversize is returned to the mills for regrinding. Normally 80 to 85 percent of the mica is recovered as a finished product. In all of the operations great care is exercised to keep the mica clean and free from oil and iron stain.

A grinding plant with 3 mills makes about 2 tons of finished product in a 10-hour day. Seven men are employed: 1 fireman, 1 millman, 1 vatman, 1 filter-press man, 2 driermen, and 1 screen and bag man. About 85 hp. is required to operate the mills, pumps, elevators, and screens in such a plant, and approximately 1/2 ton of coal is burned to dry each ton of finished product.

Dry-Grinding

Dry-grinding of scrap mica is done almost exclusively in high-speed hammer mills or pulverizers of the cage-disintegrator type equipped with screens or air separators. For satisfactory results the feed to these mills must be dry; rotary dryers are commonly used to remove excessive moisture. The discharge from the mill screens is generally elevated to multiple-deck vibrating screens which produce the sizes required. Dry-grinding of mica presents no particular problems, and the process and machinery used are generally a matter of the personal preference of the mill owner. In some installations rod mills have been used successfully for dry-grinding mica. One Canadian mill employs a grinder in which the mica is disintegrated between two horizontal steel disks, the opposing surfaces of which are provided with rows of teeth. The lower plate is stationary, while the upper plate rotates at high speed. The fine mica is discharged through an opening in the side of the machine and is conveyed to the sizing screens.

PHYSICAL PROPERTIES OF DOMESTIC AND FOREIGN MICAS

General Considerations

The suitability of domestic sheet muscovite for certain uses has been a point of controversy among producers, importers, and consumers of mica for years. Claims have been made that the domestic product is inferior to some foreign muscovites, particularly Indian musco-

vite, as a dielectric; that it heats excessively when used in condensers; and that it will not withstand as high a temperature as Indian mica without decomposition. In fact, many consumers believe that Indian mica possesses qualities not inherent in the muscovites of the United States or other countries. On the other hand, domestic producers assert that high-grade domestic sheet muscovite equals and for some uses surpasses the best Indian product. They point out that even mica experts cannot distinguish Indian mica from comparable domestic mica when similarly trimmed and that contracts specifying the Indian product are often filled wholly or in part by domestic mica without complaint from the consumer. The preference of many consumers for the Indian product is presumably based on substantial grounds, but inasmuch as Indian muscovite is virtually identical in chemical composition and mode of occurrence with that from many other countries it seems unreasonable that its physical characteristics are markedly different.

Staining and air bubbles are normally considered to impair the dielectric strength of mica greatly, but the writer's attention has been directed to so many instances in which this theory appears untrue that it seemed desirable to determine, if possible, the effect of these imperfections.

Because the questions involved are of interest to every consumer of sheet muscovite and of vital importance to many of the essential industries of the United States, should supplies of foreign mica be shut off, the author sought the aid of the National Bureau of Standards, after a search of the literature revealed a surprising lack of reliable data on the subject, to determine the differences in electrical properties, if any, in micas from various geographical sources and the effect of bubbles and stains on dielectric strength.

The Bureau of Standards gave its immediate and hearty cooperation. Not only were technicians assigned to plan and perform the tests involved, but a considerable sum was spent for special apparatus and equipment. Comparative tests were made on several hundred samples of mica representative of the major sources of the world's supply to determine their dielectric constant, power factor, dielectric strength, and physical changes on heating to elevated temperatures. Further tests were made to ascertain how stains and air bubbles in sheet mica affect its electrical properties.

Summary of Results

The results of these tests showed that there is no marked distinction between the electrical properties of micas of different geographical origin. In other words, comparable grades of mica, irrespective of source, are virtually identical as to dielectric strength and power factor. Indian muscovite certainly has no better electrical properties than comparable grades of domestic muscovite, but the preference of many users for the Indian product is apparently justified by its superior grading and better preparation for market. On the other hand, the results of the tests show that domestic muscovite generally has a slightly higher dielectric strength than Indian muscovite and is more resistant to physical changes on heating to temperatures above 600° C. The writer believes that these properties are due to the fact that the domestic mica is usually harder than the Indian product and possibly contains less water of crystallization. For most electrical uses, however, these slight advantages of domestic muscovite are more than offset by its generally poor preparation for market.

The tests also showed that heavy staining and bubbles in muscovite increase its power factor enormously and render it unfit for use in condensers. Contrary to general belief, however, moderate staining with metallic oxides apparently does not lower the dielectric strength materially. In many instances heavily stained mica in which the staining was accompanied by air bubbles showed a higher dielectric strength when tested with spherical electrodes than the best grades of clear mica. Furthermore, the presence of air bubbles does not

appear to lower the dielectric strength of mica; a large majority of the micas containing bubbles, particularly those containing clouds of microscopic bubbles, showed appreciably higher dielectric strengths when tested with spherical electrodes than those free from these imperfections. The mechanism of dielectric break-down is not understood well enough to justify the writer in attempting to explain these seeming anomolies; it may be mentioned, however, that extremely thin films or layers of gas are in general good dielectrics, as they are too thin to allow normal ionization.

As already stated, the results of the heating tests at elevated temperatures show that domestic muscovite has a higher resistance to temperatures above 600° C. than Indian muscovite. They also show the marked superiority of the soft, light-colored phlogopites over muscovites in heat resistance.

Physical properties of mica, such as its hardness, resistance to abrasion, and ability to be rolled into tubes of small diameter without cracking, which are important in many of its specialized uses, were not studied because of limited funds. It is well known, however, that these properties sometimes vary widely in mica from the same mine and that often micas from two mines in the same district may show more variation in hardness, color, flexibility, flatness, and cleavability than those from two different countries.

Reports of the tests furnished the United States Bureau of Mines by the National Bureau of Standards have been condensed and rearranged and are presented here. Some additional data, however, have been taken from Research Paper 346,[14] which describes the methods used in the electrical tests in more detail than given here. Due acknowledgments are made to the Bureau of Standards and to F. B. Silsbee, H. B. Lewis, E. L. Hall, and F. R. Caldwell, under whose direction the tests were conducted.

Measurement of Dielectric Strength of Domestic and Foreign Micas[15]

The investigation described here was undertaken by the Bureau of Standards at the request of the Bureau of Mines to determine the differences, if any, between the dielectric strength of foreign and domestic micas and the effect of staining and air bubbles on its electrical insulating value. Fifty-five samples of sheet mica, representing the major sources of the world's supply, were available for test. Of these 36 were from domestic and 19 from foreign sources.

As there is no generally accepted standard procedure for determining the dielectric strength of mica, the experimental conditions under which the tests were conducted will be specified. The size and shape of the electrodes used, as well as the nature of the surrounding medium, are of primary importance in determining the nature of the electric field to which the specimen is subjected. For testing sheet material the specifications of the American Society for Testing Materials require 2-inch flat electrodes with rounded edges, immersed in oil to prevent corona and flash-over. Some investigators have used flat electrodes embedded in porcelain and surrounded by a film of aniline to exclude air, while others have used spherical electrodes. In a preliminary investigation at the Bureau of Standards the results obtained with American Society for Testing Materials electrodes under castor oil, with 1/4-inch flat electrodes surrounded by soft rubber pads and with 1-inch spheres under light mineral oil, differed widely. Mica that had been soaked in oil for 4 days showed no appreciable change in break-down voltage. Likewise, prolonged soaking in water produced no measurable effect when all surface moisture was removed before testing.

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14 Lewis, A. B., Hall, E. L., and Caldwell, Frank R., Some Electrical Properties of Foreign and Domestic Micasand the Effect of Elevated Temperatures on Micas: National Bureau of Standards Jour. of Res., vol. 7, August 1931.

15 The tests described were conducted by A. B Lewis under the supervision of F. B. Silsbee, National Bureau of Standards.

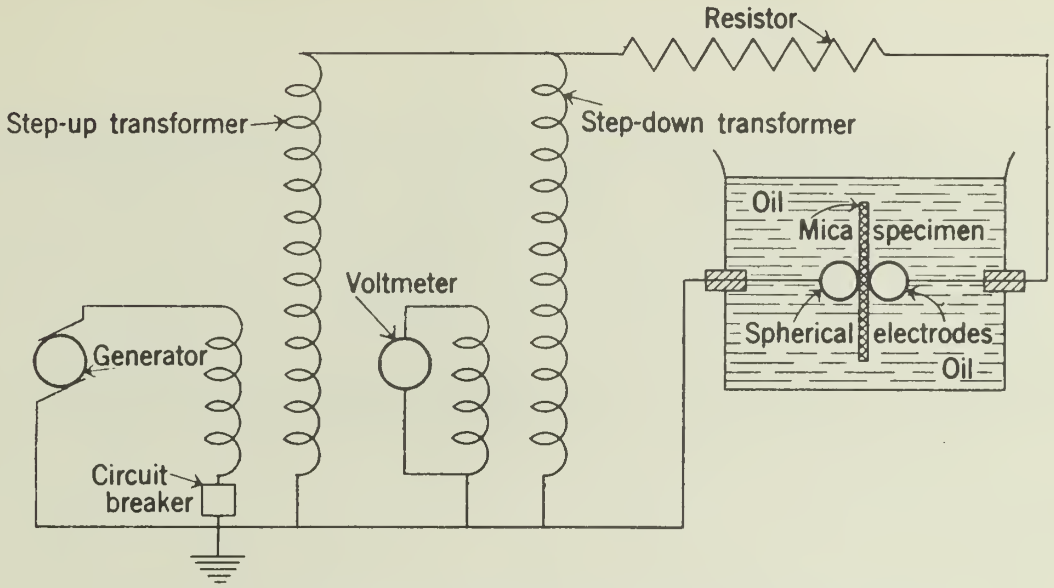

Figure 7.—Arrangement of apparatus used in determining dielectric strength of mica.

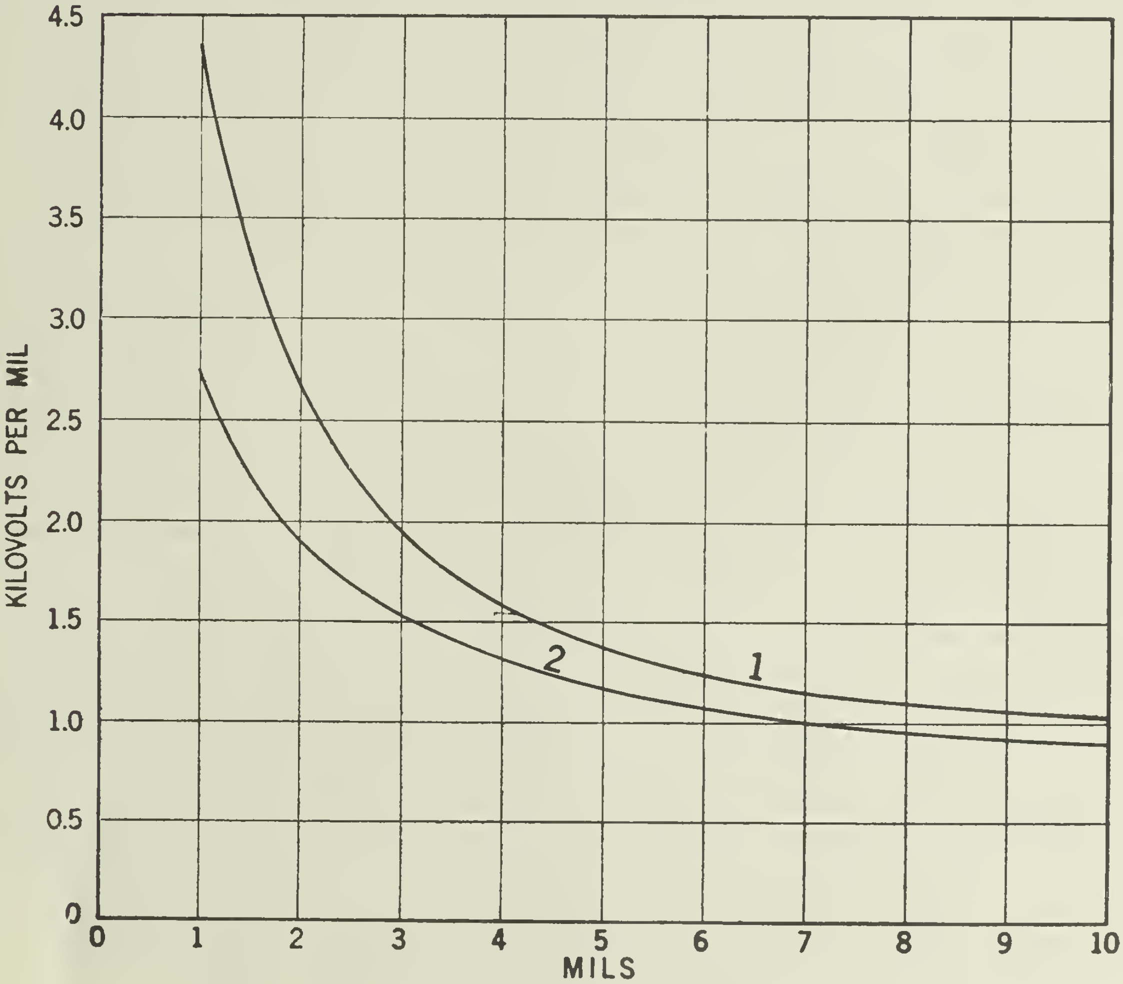

Figure 8.—Dielectric strength of a badly stained domestic mica as determined with spherical (curve 1) and with plate (curve 2) electrodes.

At ordinary power frequencies the effect of change in the frequency of the applied voltage upon the break-down voltage is probably slight. Such an effect does exist, however; Grünwald[16] found that the dielectric strength of mica at frequencies near 200,000 cycles per second is appreciably lower than at 50 cycles per second. In the light of the theories that break-down is due to formation of hot spots or hot filaments it is important to specify the time interval during which the specimen is in the electric field before break-down occurs or the rate at which the voltage is raised to the break-down point. From the foregoing it is apparent that the dielectric strengths obtained under a given set of experimental conditions, while comparable among themselves, are not necessarily in accord with the values obtained under an entirely different set of conditions.

The large number of samples to be tested made simplicity of construction and ease of manipulation important factors in the selection of apparatus. It was therefore decided to use as electrodes 1-inch spheres immersed in light mineral oil (Marcol). One sphere was connected to one high-voltage terminal of a step-up transformer which gives a maximum of 25,000 volts and is rated at 3 kv. The other side of the transformer, as well as the other sphere, was grounded. This transformer was supplied with 60-cycle voltage of virtually sine wave form. The high voltage was measured by a step-down transformer of the same ratio and rating as the supply transformer. The high-voltage coils of this standard transformer were placed in parallel with the sphere gap and the high-voltage coils of the supply transformer, and the resulting voltage was read from a voltmeter across the secondary terminals of the standard transformer. The voltage reading could be made within an accuracy of about 1 percent. This reading multiplied by the ratio of transformation of the standard transformer, which is accurately known, gives the total voltage across the specimen under test. The thickness measurements were made with a dial micrometer. A resistor of approximately 20,000 ohms was placed in series with the test specimen to prevent excessive surges in the line at the instant of break-down. Figure 7 illustrates the electric circuit used and the arrangement of the apparatus.

The foreign micas available for test were already graded. The domestic micas were graded at the Bureau of Standards. After the tests were completed all specimens were graded by the Asheville Mica Co., Biltmore, N. C.; these gradings exactly checked the original gradings. Three representative samples were taken from each lot of mica and split to thicknesses of approximately 1, 5, and 9 mils, respectively. By careful splitting it was possible to obtain specimens of sufficient size for testing in which the thickness was constant to within 0.1 or 0.2 mil over the entire surface. The uneven surface of the amber micas (phlogopites) made this measurement uncertain to about 0.5 mil on the thicker pieces.

Each specimen was inserted between the spheres and an initial low voltage applied. The voltage was then raised continuously at a rate of approximately 800 volts per second until break-down occurred. Five punctures were made on each thickness; the mean of these five observations was taken as the break-down voltage at that thickness. The average percentage deviation from the mean for each thickness was computed. The mean of the average deviations for the three thicknesses tested was thus obtained for each lot of mica. This number is the "average deviation" shown in table 9 and gives a rough idea of the reproducibility of the data and the uniformity of the mica. The three values of break-down voltage obtained for each lot were plotted against thickness, and a smooth curve was drawn through the resulting points. From this curve was read the break-down voltage (effective volts) corresponding to exactly 1, 5, and 9 mils. These are the values of break-down voltage given in table 9.

16 Grunwald, F., Arch. Elektrotechnik, vol. 12, p. 27, 1923-24.

TABLE 9.- Dielectric strength of domestic and foreign micas

DOMESTIC MUSCOVITES

Source	Classification	Average break-down voltage, kilovolts			Average deviation, percent
		1 mil	5 mils	9 mils	
Connecticut:					
Middlesex County:					
Strickland quarry, Portland	Clear, honey color	7.0	12.4	16.4	9
Georgia:					
Malden mine	Clear ruby, first quality.	5.3	10.3	11.4	7
Idaho:					
Latah County:					
Mine unknown	Black-spotted ruby	5.3	8.0	11.4	8
Maine:					
Oxford County:					
Hibbs quarry, Hebron	Clear ruby, wavy	8.3	9.1	12.4	4
Merrill mine, Paris	Clear light ruby, wavy.	4.8	9.8	11.9	3
Mine unknown	Clear light ruby	4.9	9.2	12.0	6
New Hampshire:					
Cheshire County:					
Golding-Keene quarry, Alstead	Stained ruby, wavy	6.6	8.8	13.2	9
New Hampshire Mica Co., Alstead	Clear pale green	5.8	9.4	12.9	7
Do.	Clear ruby	5.8	9.9	13.8	4
Do.	Light smoked ruby	4.7	10.1	15.4	7
North Carolina:					
Avery County:					
Huston Rock mine	Light black-spotted	5.7	10.3	15.8	6
Johnson mine	Clear ruby	5.2	9.6	11.6	3
Porter mine	Clear ruby	5.8	9.8	12.6	3
Elk mine	Clear light ruby	3.3	11.1	11.9	5
Cleveland County:					
Mine unknown	Clear ruby, first quality.	4.5	10.4	14.2	13
Gaston County:					
Mine unknown	Clear ruby	6.0	10.1	14.6	6
Haywood County:					
Big Ridge mine	do.	6.3	12.8	17.4	7
Mitchell County:					
Hawk mine	do.	8.5	11.3	15.5	4
English Knob mine	Clear dark green	6.2	8.9	12.2	4
Hoot Owl mine	Black-spotted	3.8	9.2	14.6	7
Deer Park mine	Clear dark green	5.5	10.0	12.4	6
Abernathy mine	Clear ruby	5.1	11.4	14.2	6
Watagua County:					
Mine unknown	Clear water, wavy	6.0	12.3	15.4	10

TABLE 9.- Dielectric strength of domestic and foreign micas - Continued

DOMESTIC MUSCOVITES - Continued

Source	Classification	Average break-down voltage, kilovolts			Average deviation, percent
		1 mil	5 mils	9 mils	
North Carolina - Continued:					
Yancey County:					
Presley mine	Clear ruby, wavy	5.7	10.5	15.2	5
Barger mine	Clear water	7.0	9.4	11.5	6
Mine in Pisgah National Forest	Clear ruby, wavy	5.5	8.8	11.7	7
Gibbs mine	Clear water	5.4	9.4	10.4	5
Poll Hill mine	Light black-spotted	5.1	9.6	11.1	7
Balsam mine	Clear ruby	4.9	9.0	13.7	8
Fanny Gouge mine	Clear water	5.0	10.5	12.5	8
Do.	Black-stained	5.2	10.4	11.9	5
Cat Tail mine	Clear ruby, wavy	5.7	9.5	13.8	5
Westall mine	Clear light ruby	5.1	9.0	12.8	6
South Dakota:					
Custer County:					
John Wells mine, Sylvan Lake	Heavy-smoked ruby	3.7	10.8	17.9	5
Prospect 2 miles southeast of Custer	Stained ruby	5.0	8.3	10.9	5
Climax mine	Clear ruby	5.1	8.7	10.7	3

FOREIGN MUSCOVITES

Argentina:					
Mine unknown	Black-stained	5.4	7.0	9.8	6
Do.	Light black-spotted	5.1	9.5	12.3	3
Brazil:					
Mine unknown	Clear and slightly stained.	6.0	8.7	11.4	3
Mine unknown	Clear and slightly stained.	6.0	8.7	11.4	3
Guatemala:					
Mine unknown	Clear dark green	5.0	12.8	16.3	10
India:					
Kodarma, Bihar (average of 7 samples)	Clear and slightly stained ruby.	6.2	8.6	10.9	4
Ganwan, Bihar (average of 6 samples)	do.	4.3	7.9	11.0	4
Mine unknown (average of 2 samples)	Clear ruby	4.4	8.9	12.1	5
Mine unknown	Fair-stained ruby	5.4	12.3	14.4	7
Do.	Stained ruby	5.3	11.4	15.8	6
Do.	Heavy-stained ruby	6.7	11.2	13.9	6
Do.	Black-spotted	5.3	8.6	13.1	7
Madras:					
Mine unknown	Red- and black-stained green.	3.9	8.9	9.5	8
Union of South Africa:					
Mine unknown	Clear water, first quality.	5.0	10.9	15.6	5

TABLE 9.- Dielectric strength of domestic and foreign micas - Continued

FOREIGN MUSCOVITES - Continued

Source	Classification	Average break-down voltage, kilovolts			Average deviation, percent
		1 mil	5 mils	9 mils	
Union of South Africa - Continued:					
Mine unknown	Red-stained	4.6	9.3	12.6	7

FOREIGN PHLOGOPITES

Source	Classification	1 mil	5 mils	9 mils	Average deviation, percent
Canada:					
Quebec:					
Lucky Reserve mine	Brown amber	4.5	10.2	12.1	6
Cantley, Cliff mine	do.	4.3	10.5	11.8	7
Madagascar:					
Mine unknown	Hard black amber	5.9	12.7	16.4	6
Do.	Medium soft amber	5.3	10.8	13.0	5

Table 10 collates the dielectric strengths listed in the preceding table according to the quality of the mica and the country of its origin. A study of this table discloses many surprising results. First, the average dielectric strength of 19 samples of clear domestic mica, all from different mines and from 5 States, is superior to the average shown by 15 samples of clear and slightly stained Indian mica. As this result is confirmed by the dielectric strengths of eight other samples of clear domestic mica, it is evident that the often quoted "superior dielectric strength of Indian mica" is not premised upon fact.

On the other hand, although the tests clearly demonstrate superiority in the dielectric strength of clear domestic mica as compared with that of clear and slightly stained Indian mica the author hesitates to draw a final conclusion because of the unavoidable scattering of results shown by the average deviations listed in table 9. Possibly, however, the seeming superiority in the dielectric strength of clear domestic mica may be due to its usual greater hardness or some other undetermined factor.

Comparison of the dielectric strengths of muscovite samples from Argentina, Brazil, Guatemala, and South Africa shows that in most tests these micas yielded excellent values and that they are probably as well suited for dielectric uses as domestic or Indian mica. The clear dark-green Guatemalan muscovite showed particularly high dielectric strengths at thicknesses of 5 and 9 mils, but the heavy red- and black-stained green Madras mica gave low resultsat all three thicknesses. The few samples of phlogopite tested showed average results, equal to those obtained with muscovite; the 2 samples of Madagascan muscovite exhibited excellent dielectric strengths, exceeding those of the 2 samples of Canadian amber mica at all thicknesses. The conclusion that Madagascan amber mica is superior to the Canadian as a dielectric is unjustified, however, because of the few samples tested.

The results obtained with stained mica indicate that, contrary to general belief, moderate staining with metallic oxides does not materially impair dielectric strength. Where staining, and in some instances even heavy staining, is accompanied by air bubbles the dielectric strength of the mica usually exceeds that of clear mica without air bubbles. For example, the 5 stained micas listed below, containing air bubbles in quantity, show dielectric strengths at all thicknesses superior to the average values of the 15 samples of clear and slightly stained Indian mica.

TABLE 10.- Dielectric strength of mica according to quality and country of origin

DOMESTIC MUSCOVITE

Classification	Number of samples	Average break-down voltage, kilovolts 1 mil	5 mils	9 mils
Clear ruby	19	5.6	10.0	13.2
Clear water	4	5.9	10.4	12.5
Clear pale green	1	5.8	9.4	12.9
Clear dark green	2	5.9	9.5	12.3
Clear honey	1	7.0	12.4	16.4
Stained ruby	2	5.8	8.6	12.1
Light black-spotted	2	5.4	10.0	13.5
Black-spotted	2	4.6	8.6	13.0
Black-stained	1	5.2	10.4	11.9
Light-smoked ruby	1	4.7	10.1	15.4
Heavy-smoked ruby	1	3.7	10.8	17.9
FOREIGN MUSCOVITE				
India, clear and slightly stained	15	5.2	8.4	11.1
Brazil, clear and slightly stained	1	6.0	8.7	11.4
Guatemala, clear dark green	1	5.0	12.8	16.3
Union of South Africa, clear water	1	5.0	10.9	15.6
India, fair-stained ruby	1	5.4	12.3	14.4
India, stained ruby	1	5.3	11.4	15.8
Argentina, light black-spotted	1	5.1	9.5	12.3
Argentina, black-stained	1	5.4	7.0	9.8
Union of South Africa, red-stained	1	4.6	9.3	12.6
India, heavy-stained ruby	1	6.7	11.2	13.9
India, black-spotted	1	5.3	8.6	13.1
India (Madras), red- and black-stained green	1	3.9	8.9	9.5
FOREIGN PHLOGOPITE				
Canada, brown amber	2	4.4	10.3	11.9
Madagascar, hard black amber	1	5.9	12.7	16.4
Madagascar, medium soft amber	1	5.3	10.8	13.0

Classification	1 mil	5 mils	9 mils
Domestic, light black-spotted	5.4	10.0	13.5
Domestic, black-stained	5.2	10.4	11.0
India, black-spotted	5.3	8.6	13.1
India, stained ruby	5.3	11.4	15.8
India, heavy-stained ruby	6.7	11.2	13.9

The results on some of the stained micas containing air bubbles were so surprising that they were checked and rechecked by further tests on additional specimens. Other micas were examined to determine if high dielectric strength, particularly at thicknesses of 5 and 9 mils, where the bubbles were not split out, coincided with the occurrence of numerous bubbles in the mica. Such a result was observed in a majority of the tests, and the highest dielectric strength (17.9 kv.) recorded in any of the tests at 9 mils was found in a "heavy-smoked ruby" mica from the Black Hills of South Dakota. Examination of this sample under a microscope revealed that the smoky effect was caused by clouds of innumerable minute bubbles.

This discovery of an apparent relation between high dielectric strength and the presence of air bubbles led to the classification of the specimens according to their air-bubble content. The curves shown in figure 9 were obtained by plotting the average dielectric strengths of four groups of muscovite specimens as classified by the Bureau of Standards.[17] Curves 1 and 2 represent the average values of 18 lots of domestic clear ruby mica and 9 lots of stained domestic ruby mica containing air bubbles. Curves 3 and 4 similarly represent average values of 3 lots of Indian clear ruby mica and 4 lots of Indian stained ruby mica containing air bubbles. In both sets of curves the dielectric strength of the mica containing stains and air bubbles is superior at all thicknesses to that of mica free from these imperfections.

It is believed that these surprising results are caused largely by the air bubbles and that staining alone will not produce them. This theory is borne out by the fact that specimens of stained mica apparently free from bubbles showed lower dielectric strengths than clear micas. Again, micas containing air bubbles but little or no staining showed unusually high dielectric strengths, for example, the ruby mica from South Dakota previously mentioned.

All of the above conclusions, however, are apparent rather than final, as the author realizes the danger of drawing general deductions from a small number of tests conducted under only one set of experimental conditions.

Special attention is called to the fact that the data in tables 9 and 10 are the results obtained with the particular method of test described. If the tests had been made with the 2-inch plate electrodes specified by the American Society for Testing Materials[18] for sheet insulating material the values would have been lower than those shown, as the plate electrodes find the weakest point in more than 3 square inches of mica as compared with a comparatively minute area tested by the spherical electrodes. Nevertheless, the relative values obtained with these two types of electrodes on fairly homogeneous material are in fair accord. For example, the following values of dielectric strength of a badly stained domestic ruby mica from the Fanny Gouge mine, Yancey County, N. C., and a clear Indian ruby mica were obtained in comparative tests with these different electrodes.

The results of the two methods of test on the badly stained domestic mica are plotted in curves 1 and 2, figure 8, which show but slight variations, although the vertical coordinates in the plot have been purposely doubled to emphasize any differences.

As the results obtained in these tests with different types of electrodes were so closely parallel it was decided to run a series of tests on some of the same mica that had been previously tested with spherical electrodes to discover the influence of bubbles and staining on the dielectric strength as determined with 2-inch plate electrodes. Fourteen different muscovites, classified as clear, containing bubbles, and black or heavy-stained mica, were selected for these tests. The specimens were immersed in castor oil to prevent corona and flash-over and tested with a 60-cycle alternating voltage of virtually sine wave form. Table 12 records the results of the individual tests on each specimen of mica.

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17 See footnote 15, p. 414.

18 American Society for Testing Materials, Short-Time Dielectric Strength Test: Tentative Method D149-33T.

TAB:E 11.- Dielectric strength of two micas as determined with spherical and with plate electrodes

BADLY STAINED DOMESTIC RUBY MICA

Thickness, mils	Dielectric strength, kilovolts per mil	
	Spherical 1-inch electrodes	A.S.T.M. 2-inch plate electrodes
1	4.35	2.75
2	2.65	1.90
3	1.95	1.52
4	1.58	1.34
5	1.39	1.19
6	1.25	1.10
7	1.15	1.03
8	1.10	1.00
9	1.08	.93
10	1.02	.90

CLEAR INDIAN RUBY MICA

4	2.00	1.42
5	1.72	1.26
6	1.55	1.10

TABLE 12.- Dielectric strength of various muscovites as determined with plate electrodes

Source	Classification	Thickness, mils	Break-down voltage, kilovolts
Strickland quarry, Connecticut	Clear ruby	2.2	5.60
		2.9	4.80
		5.0	7.10
Cleveland County, N.C.	do.	1.8	4.90
		5.1	6.50
		8.3	9.40
Hawk mine, Mitchell County, N.C.	do.	2.1	3.90
		3.9	6.20
		9.0	8.20
Gibbs mine, Yancey County, N.C.	do.	6.1	7.60
Malden mine, Georgia	do.	1.2	3.50
		1.8	5.10
		5.2	7.40
		7.0	8.70
		8.8	9.20

TABLE 12.- Dielectric strength of various muscovites as determined with plate electrodes - Continued

Source	Classification	Thickness, mils	Break-down voltage, kilovolts
Hibbs quarry, Oxford, Maine	Clear ruby	1.3	3.50
		3.1	5.10
		6.0	7.10
		10.0	8.60
		10.5	9.50
Strickland quarry, Connecticut	Clear, honey color, containing many bubbles.	1.1	3.07
		2.5	4.55
		6.4	7.24
		11.9	9.25
		11.9	10.40
India	Ruby, heavily stained and containing many air bubbles.	1.1	3.07
		2.2	4.60
		3.1	5.07
		5.5	6.80
		6.6	7.62
		8.2	7.85
		9.4	8.18
John Wells mine, South Dakota	Ruby, containing clouds of minute bubbles.	2.2	4.16
		3.1	4.71
		3.8	5.32
		4.6	5.92
		8.3	8.31
Africa	Red-stained	1.7	4.00
		2.2	3.04
		5.9	8.02
		7.2	8.96
		7.2	7.85
		7.8	8.64
Do.	Black-stained	2.0	3.48
		4.7	5.10
		6.6	7.19
		6.6	7.10
Argentine	do.	.9	2.93
		2.7	4.93
		4.7	6.36
		4.7	6.02
		10.0	8.78
Do.	do.	.7	2.11
		1.6	3.34
		3.8	5.04
		5.2	5.86
		5.7	6.03
		10.0	8.79
India	do.	1.4	2.96
		1.8	3.78
		4.6	6.24
		5.1	6.08
		8.9	8.48

The results obtained on the six clear micas were plotted as break-down voltages in kilovolts against thickness in mils, and a smooth curve was drawn through the resulting points. The results obtained on the 3 micas containing bubbles and on the 5 micas with black or heavy staining were similarly plotted. From the smooth curves representing the 3 different groups of mica break-down voltages were read at exactly 1, 3, 5, 7, and 9 mils. These values, together with the dielectric strength in kilovolts per mil, are recorded in table 13.

TABLE 13.- Dielectric strength of various classifications of muscovite as determined with plate electrodes

CLEAR MICA (6 specimens, 20 tests)

	Thickness, mils				
	1	3	5	7	9
Break-down voltage, kilovolts	3.25	5.35	6.80	7.95	8.94
Dielectric strength, kilovolts per mil	3.25	1.78	1.36	1.14	.99
MICA CONTAINING BUBBLES (3 specimens, 17 tests)					
Break-down voltage, kilovolts	3.00	4.82	6.35	7.58	8.61
Dielectric strength, kilovolts per mil	3.00	1.61	1.27	1.08	.96
BLACK AND HEAVY-STAINED MICA (5 specimens, 26 tests)					
Break-down voltage, kilovolts	2.62	4.44	6.10	7.55	8.90
Dielectric strength, kilovolts per mil	2.62	1.48	1.22	1.08	.99

Inspection of table 13 shows that the clear micas have a slightly greater average dielectric strength than those containing bubbles and that these last in turn show a higher average dielectric strength than the group of black and heavy-stained micas. The differences however, are slight, particularly at thicknesses of 5 mils and over, and at 9 mils they virtually disappear.

The results with the 2-inch plate electrodes unquestionably represent the voltage a mica would withstand in most instances of actual use much more exactly than those obtained with spherical electrodes; the writer therefore urges the general adoption of the 2-inch plate electrodes, used in accordance with the method recommended by the American Society for Testing Materials, as standard for determining the dielectric strength of micas.

Power Factors of Micas[19]

The power factor of mica is the ratio (usually expressed as percent) of the total power loss in a condenser in which it is the dielectric to the total volt-amperes supplied the condenser. The extent to which mica will heat and its power loss under an electric load are of great importance if the mica is to be used in condensers. Direct measurement of the heat generated when a mica is electrically charged is impracticable, but the power factor furnishes a reliable guide as to the amount of this heat. A mica with a high power factor will generate much heat and one with a low power factor, little heat. The power factor of a mica therefore determines its suitability for use in condensers.

19 The tests described were planned by and conducted under the supervision of E. L. Hall, National Bureau of Standards.

In view of the lack of trustworthy data from which a comparison of the power factors of domestic and foreign mica might be made, the National Bureau of Standards agreed to make the required tests and spent a considerable sum in building an electrically shielded room in which to conduct them and in assembling special apparatus. The data submitted are the results of measurements upon both domestic and foreign micas to determine their relative suitability for use in electrical condensers for radio frequencies.

The power loss was measured by determining the resistance of a circuit containing a condenser prepared from an individual sheet of mica and again measured after the sample condenser was replaced by a standard condenser whose losses were either negligible or known. The difference between the two measurements gives the resistance of the sample condenser. The power factor in percent is then calculated from the equation:

$$\text{Power factor (percent)} = 6.283 \times RCf \times 10^{7},$$

where

$\underline{R}$ = resistance of the sample in ohms,
$\underline{C}$ = capacitance of the sample in micromicrofarads,
$\underline{f}$ = frequency in kilocycles per second at which the measurement was made.

The dielectric constant was also calculated from the observed data by the following equation:

$$\underline{K} = 11.3\ Ct/\underline{S},$$

where

$\underline{K}$ = the dielectric constant,
$\underline{C}$ = capacitance of the sample in micromicrofarads,
$\underline{t}$ = thickness of the sample in centimeters,
$\underline{S}$ = area of sample in square centimeters.

The dielectric constant of mica is the ratio of the capacitance of a condenser in which it is the dielectric to the capacitance of a similar condenser in which the dielectric is a vacuum.

Further details of the method of measurement may be found in Bureau of Standards Scientific Paper 471, Methods of Measurement of Properties of Electrical Insulating Materials, and in the American Society for Testing Materials specifications, Tentative Methods of Testing Electrical Insulating Materials for Power Factor and Dielectric Constant at frequencies of 100 to 1,500 kilocycles, A.S.T.M. Designation D150-27T.

Test condensers were made by applying linseed oil to both sides of a mica sheet and then wiping the surfaces lightly with a clean, dry cloth. One side of the mica was coated with tinfoil, the thin film of linseed oil causing the foil to adhere tightly. One or two pieces of tinfoil 3 by 4 cm were then attached to the opposite side of the mica in the same manner. Care was taken to apply these small tinfoil plates to sections free from air pockets and of apparent uniformity. Two pieces of tinfoil on one side gave two test condensers for a given mica sample, although measurements were not made on all the condensers thus prepared. The capacity of the condenser was first measured on a direct-reading microfarad meter at 500 cycles per second. This measurement was of value in starting the measurements at radio frequencies. Readings of the relative humidity and the temperature of the room were also taken at the time of the measurements at radio frequencies.

Power-factor measurements were made on most samples at four frequencies between 100 and 1,000 kc. A few tests on some of the heavy-stained micas immediately indicated their unsuitability for use in condensers for radio purposes, so only a few of the heavy-stained samples were tested. No attempt was made to study the effect on the power factor caused by changes in temperature or humidity, which are known to alter its value. Tables 14 and 15 list the results of the tests.

TABLE 14.- Power factors and dielectric constants of domestic and foreign micas

MUSCOVITES

Origin of sample	Quality	Temperature, °C.	Relative humidity, percent	Thickness, mm	Area of sample, cm^2	Frequency, kc	Dielectric constant, k	Power factor, percent
Big Ridge mine, Haywood County, N.C.	Clear	24.5	37.2	0.106	12.06	108.2	6.58	0.01
		25.0	37.2			242.8	6.58	.01
		25.1	37.2			544.0	6.57	.02
		25.2	37.2			778.0	6.57	.02
		25.2	37.2			1,010.0	6.57	.03
Do.	do.	22.8	23.5	.175	12.09	134.5	6.99	.01
		23.0	23.5			300.0	6.99	.01
		23.3	23.5			675.0	6.99	.01
		23.5	23.5			962.0	6.99	.02
Hibbs quarry, Oxford County, Me.	do.	25.9	16.0	.340	12.09	178.0	7.37	.01
		26.0	16.0			401.0	7.37	.01
		....	32.0			401.0	7.37	.01
		23.5	27.5			608.1	7.34	.01
		25.9	16.0			900.0	7.34	.01
Johnson mine, Avery County, N.C.	do.	24.4	31.0	.358	12.09	185.6	7.09	.01
		24.4	31.0			419.5	7.09	.01
		24.4	31.0			620.0	7.09	.02
		25.0	30.0			940.0	7.11	.01
Do.	do.	24.9	30.0	.358	12.09	185.6	7.11	.02
		24.6	30.0			419.0	7.11	.02
		24.3	30.0			619.0	7.11	.02
		24.0	30.0			942.0	7.11	.02
Malden mine, Upson County, Ga.	do.	27.2	47.0	.198	12.11	141.0	7.00	.01
		27.1	47.0			315.0	7.00	.01
		27.6	47.0			482.0	7.00	.01
		27.4	47.0			710.0	7.00	.01
Westhall mine, Yancey County, N.C.	do.	23.8	30.1	.246	12.20	155.0	7.15	.01
		24.1	30.0			262.5	7.16	.01
		24.3	30.1			529.0	7.15	.01
		24.6	30.1			782.0	7.16	.01
Do.	do.	23.8	30.1	.246	12.20	154.8	7.16	.01
		24.0	30.1			262.1	7.16	.01
		24.3	30.1			528.0	7.16	.01
		24.5	30.1			781.0	7.16	.02

TABLE 14.- Power factors and dielectric constants of domestic and foreign micas - Continued

MUSCOVITES - Continued

Origin of sample	Quality	Temperature, °C.	Relative humidity, percent	Thickness, mm	Area of sample, cm^2	Frequency, kc	Dielectric constant, k	Power factor, percent
Alexandria, N.H.	Clear	25.7	66.5	0.195	12.04	140.2	7.10	0.02
		25.7	66.5			314.0	7.10	.02
		25.8	66.5			704.0	7.11	.03
		25.9	66.5			1,006.0	7.11	.03
India	do.	25.8	47.0	.183	12.14	135.0	7.16	.01
		26.1	47.0			302.0	7.16	.01
		26.1	47.0			677.0	7.16	.01
		26.3	47.0			966.0	7.16	.01
Do.	do.	26.2	25.0	.091	12.01	120.0	7.91	.01
		26.2	25.0			305.0	7.90	.01
		26.2	25.0			658.0	7.90	.03
		26.2	25.0			861.0	7.90	.01
Do.	do.	25.0	30.3	.270	12.28	160.3	7.16	.01
		25.0	30.3			278.0	7.16	.01
		25.0	30.3			548.0	7.16	.01
		25.0	30.3			812.0	7.16	.01
Do.	do.	25.5	59.5	.190	11.96	139.0	7.06	.02
		25.3	59.5			311.0	7.06	.02
		25.4	59.5			700.0	7.06	.02
		25.5	59.5			1,000.0	7.08	.03
Guatemala	Clear green.	26.3	....	.280	12.09	165.0	7.17	.07
		26.4	....			556.0	7.17	.04
		26.4	55.0			826.0	7.19	.03
		26.4	55.0			1,550.0	7.17	.03
Ruggles mine, N.H.	Clear with a few air bubbles.	24.8	57.0	.351	12.10	181.0	7.32	.11
		25.0	57.0			307.0	7.33	.09
		25.2	57.0			608.0	7.33	.07
		25.4	57.0			914.0	7.32	.06
Fanny Gouge mine, Mitchell County, N.C.	Slightly stained.	23.0	31.0	.160	12.33	138.0	5.84	.21
		23.2	31.0			309.0	5.84	.16
		24.2	31.0			694.0	7.07	.12
		24.2	31.0			995.0	5.86	.11
		24.2	31.0			2,000.0	5.83	.08
Do.	do.	23.6	44.0	.175	12.33	126.5	7.69	.01
		23.6	44.0			283.0	7.69	.02
		23.6	44.0			634.0	7.69	.02
		23.6	44.0			911.0	7.69	.03
		23.6	44.0			911.0	7.69	.03
Hibbs quarry, Oxford County, Me.	do.	25.5	37.2	.216	12.06	147.5	6.98	.02
		25.3	37.2			330.0	6.98	.02
		25.5	37.2			503.0	6.98	.02
		25.5	37.2			742.0	6.98	.02
		25.6	37.2			1,067.0	6.98	.03

TABLE 14.- Power factors and dielectric constants of domestic and foreign micas - Continued

MUSCOVITES - Continued

Origin of sample	Quality	Temperature, °C.	Relative humidity, percent	Thickness, mm	Area of sample, cm^2	Frequency, kc	Dielectric constant, k	Power factor, percent
G. E. Co., Alexandria, N.H.	Slightly stained.	25.3	60.5	0.140	12.12	121.0	6.87	0.03
		25.5	60.5			281.0	6.87	.03
		25.5	60.5			614.0	6.87	.04
		25.5	60.5			870.0	6.87	.04
Do.	do.	23.8	27.5	.208	12.31	143.8	7.04	.02
		23.0	27.5			321.0	7.04	.03
		23.4	27.5			488.5	7.04	.03
		23.4	29.0			723.0	7.04	.03
Fanny Gouge, Mitchell County, N.C.	Heavily stained.	23.2	...	.210	11.63	227.0	8.64	(1)
		23.2	...			304.0	8.64	(1)
Do.	Heavily stained.	23.0	43.0	.210	11.99	180.5	7.18	1.39
		26.0	43.0			181.0	7.16	1.40
		26.0	43.0			325.0	7.12	1.20
		23.0	43.0			325.0	7.16	1.18
		23.0	43.0			732.0	7.11	.94
		26.0	43.0			733.0	7.21	1.10
		23.2	43.0			1,047.0	7.10	.81
		26.0	43.0			1,050.0	7.09	1.10
		24.4	43.0			1,050.0	7.09	.82
Do.	do.	...	...	.210	12.03	310.0	7.94	5.4
Do.	do.	24.8	...	.190	12.09	119.5	9.64	(1)
Argentine	do.	24.8	49.0	.098	12.11	464.0	8.83	8.36
India	do.	24.5	34.0	.396	12.26	117.5	8.48	(1)
		24.5	34.0			302.0	8.39	(1)
		24.5	34.0			924.0	8.00	(1)

PHLOGOPITES (AMBER MICAS)

Origin of sample	Quality	Temperature, °C.	Relative humidity, percent	Thickness, mm	Area of sample, cm^2	Frequency, kc	Dielectric constant, k	Power factor, percent
Madagascar	Hard, clear, pale green.	28.2	62.5	0.142	12.12	129.4	7.07	1.12
		28.8	62.5			290.0	6.04	.75
		28.7	62.5			661.0	5.77	.47
		38.5	62.5			928.0	5.77	.38
Do.	Soft, opaque.	26.5	...	.292	12.12	190.0	5.41	7.12

[1]Losses were too large to measure conveniently.

TABLE 15.- Summary of power factors and dielectric constants of micas tested

Number of samples	Origin	Kind	Dielectric constant Average	Dielectric constant Spread	Power factor Average	Power factor Spread
9	United States	Clear muscovite	7.06	6.57-7.37	0.014	0.01-0.3
4	India	do.	7.32	7.06-7.91	.014	.01- .03
1	Guatemala	Clear green muscovite	7.18	7.17-7.19	.04	.03- .07
1	New Hampshire	Unstained muscovite with air bubbles.	7.33	7.32-7.33	.08	.06- .11
5	United States	Slightly stained muscovite	6.93	5.83-7.69	.04	.01- .21
2	do.	Heavy-stained muscovite	7.22	7.09-7.94	1.53	.82-5.4
1	Argentina	do.	8.83	....	8.36	....
1	India	do.	8.29	8.00-8.48	(1)	(1)
2	Madagascar	Phlogopite	....	5.41-7.07	....	.38-7.12

[1]Losses were too large to measure conveniently.

The tests show that the power factor of clear domestic mica compares favorably with that of the best Indian product; in fact both the average power factor and the spread of power-factor values obtained from 9 samples of clear domestic mica are identical with those of the 4 lots of clear Indian mica tested. The measurements on 5 lots of slightly stained muscovites and 1 sample containing a few air bubbles show that these grades of mica are unsuited for condensers at radio frequencies. Heavy-stained muscovite and phlogopite yielded such high power factors as to preclude their use for condensers.

With the heavy-stained muscovites, the phlogopites, the clear domestic muscovite containing air bubbles, and the clear Guatemalan mica, the power factor is a function of the frequency, decreasing as the frequency increases. There is no evidence, however, that the dielectric constant is a function of frequency or that there is any close relation between the amount of staining and the dielectric constant.

The tests entirely disprove the frequent assertion that domestic mica is inferior to Indian for use in radio condensers. Only the best grades of the Indian product are used for condenser films and, of course, the best domestic micas must be selected to compare with them.

Physical Changes in Micas When Heated to Elevated Temperatures[20]

Heating tests were conducted by the Bureau of Standards on 19 lots of foreign and domestic micas furnished by the writer to determine how they would withstand elevated temperatures. Of these micas 6 were domestic muscovites, 1 domestic biotite, 3 Indian micas, 1 Guatemalan muscovite, 1 Brazilian muscovite, 3 Canadian phlogopites, and 4 Madagascan phlogopites.

The mica was cut into rectangles, 1 by 2.5 cm, and split to thicknesses of 2 to 4 mils, all samples of each lot being of the same thickness. Eight samples were selected to represent each lot. One of these was not treated. The rest were sorted into 7 groups with similar specimens from the other 18 lots of mica, making 7 groups of 19 samples each. The various groups were heated on an alumina plate in a furnace of sensibly uniform temperature to 600°, 700°, 800°, 900°, 1,000°, 1,100°, and 1,200° C., respectively, and held at these temperatures for one half hour. The temperatures were measured with a pyrometer and are accurate to within - 10° C.

20 The tests described were planned by and conducted under the supervision of Frank R. Caldwell, National Bureau of Standards.

The rate of heating was rapid, the time required to reach the test temperatures ranging from about 35 minutes in the test at 600° C. to about 1 1/2 hours in the one at 1,200° C. No external force was applied to the samples during the tests. Thus the deformations and changes in other properties observed are due only to exposure to the various temperatures to which the specimens were subjected. Changes in the properties of the mica caused by the heating are shown in table 16. The properties listed are:

1. Color graded from 1 (very light) to 7 (very dark).
2. Condition of surface graded from 1 (glassy) to 7 (very rough), A (slightly wrinkled), B (badly wrinkled), C (slightly checked), and D (badly checked).
3. Opacity graded from 1 (clear) to 7 (opaque).
4. Separation of laminae graded from 1 (no separation) to 5 (extreme separation) and in some cases A (slightly sintered).
5. Structure graded from 1 (withstands bending) to 4 (does not withstand bending), A (hard) and B (soft).
6. Size before and after heating.

TABLE 16.- Results of heating micas to elevated temperatures

CLEAR MUSCOVITE, ALEXANDRIA MINE, N.H.

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal	1 yellow	1	2	1	1A	25 by 10 by 0.2
600	1 yellow, brown stains.	1	2	1	1A	25 by 10 by 0.2
700	3 gray, brown stains.	2	3	1	1A	25 by 10 by 0.2
800	5 gray	2	7	2	3C	25 by 10 by 0.7
900	5 brownish gray	2	7	2	3C	25 by 10 by 0.7
1,000	2 brown, dark stains.	3	7	3	4B	25 by 10 by 1
1,100	2 gray, brown stains.	3	6	2	4A	25 by 10 by 0.5
1,200	2 gray	5	6	B	4A	25 by 10 by 0.5

CLEAR MUSCOVITE, ABERNATHY MINE, N.C.

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal	2 gray	1	4	1	1A	25 by 10 by 0.3
600	3 gray	1	4	1	1A	25 by 10 by 0.3
700	5 gray	1	5	1	1A	25 by 10 by 0.3
800	4 gray	2	7	3	3B	25 by 10 by 1.5
900	do.	2	7	4	3C	25 by 10 by 2.5
1,000	do.	2	7	3	3C	25 by 10 by 2
1,100	do.	5	7	2A	4A	25 by 10 by 1
1,200	2 brown	6B	7	B	4A	24 by 8 by 1.5 (warped)

TABLE 16.- Results of heating micas to elevated temperatures - Continued

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
	CLEAR MUSCOVITE, HIBBS QUARRY, ME.					
Normal	2 pinkish gray	1	3	1	1A	25 by 10 by 0.3
600	2 gray	1	3	1	1A	25 by 10 by 0.3
700	3 gray, brown stain.	1	3	1	1A	25 by 10 by 0.3
800	5 gray	2	7	4	3B	25 by 10 by 1.5
900	do.	2	7	4	3B	25 by 10 by 1.5
1,000	1 gray	2	6	3	3A	25 by 10 by 1.5
1,100	do.	3	6	2A	4A	25 by 10 by 1
1,200	White	6B	7	B	4A	22 by 9 by 1.5 (warped)
	CLEAR MUSCOVITE, SYLVAN LAKE, S.DAK.					
Normal	2 pink	1	4	1	1A	25 by 10 by 0.3
600	2 gray	1	3	1	1A	25 by 10 by 0.3
700	3 gray	1	5	1	1A	25 by 10 by 0.3
800	5 gray	3	7	4	2B	25 by 10 by 3
900	4 gray	2	7	4	3B	25 by 10 by 2
1,000	1 gray	2	6	4	3C	25 by 10 by 2
1,100	do.	3	6	3	4A	25 by 10 by 1.5
1,200	White	6B	7	B	4A	23 by 8 by 0.5 to 3 (warped).
	CLEAR GREEN MUSCOVITE, GUATEMALA					
Normal	5 green	1	4	1	1A	25 by 10 by 0.3
600	6 green	1	5	1	1A	25 by 10 by 0.3
700	2 green	1	6	2	1A	25 by 10 by 0.3
800	6 greenish brown	3	7	4	3C	25 by 10 by 3
900	6 brown	2	7	4	3C	25 by 10 by 2.5
1,000	do.	2	7	4	3C	25 by 10 by 3.5
1,100	3 brown	5Bd	7	4	4C	25 by 10 by 3
1,200	do.	7	7	B	B	14 by 4 by 5
	CLEAR MUSCOVITE, INDIA					
Normal	3 pinkish gray	1	4	1	1A	25 by 10 by 0.4
600	2 gray	1	2	1	1A	25 by 10 by 0.4
700	do.	2	5	1	2B	25 by 10 by 0.4
800	5 gray	3	7	4	3C	25 by 10 by 3.5
900	4 gray	2	7	4	3C	25 by 10 by 3
1,000	1 gray	2	6	4	3C	25 by 10 by 3
1,100	do.	2	7	3	4C	25 by 10 by 2
1,200	do.	2	7	3	4A	25 by 10 by 2

TABLE 16.- Results of heating micas to elevated temperatures - Continued

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
CLEAR MUSCOVITE, CLIMAX MINE, S.D.						
Normal	3 pinkish gray	1	3	1	1A	25 by 10 by 0.3
600	3 gray	1	3	1	1A	25 by 10 by 0.3
700	do.	1	4	1	1A	25 by 10 by 0.3
800	5 gray	2	7	4	2B	25 by 10 by 2
900	4 gray	2	7	4	3B	25 by 10 by 2
1,000	1 gray	2	6	4	3B	25 by 10 by 2
1,100	do.	2	6	3	4B	25 by 10 by 1.5
1,200	do.	3	6	2	4A	25 by 10 by 1
CLEAR MUSCOVITE, AVON, IDAHO						
Normal	2 gray	1	3	1	1A	25 by 10 by 0.4
600	4 gray	1	4	1	1A	25 by 10 by 0.4
700	5 gray, brown stains.	2	7	3	2A	25 by 10 by 1
800	do.	2	7	3	3B	25 by 10 by 1.5
900	do.	2	7	3	3C	25 by 10 by 1.5
1,000	3 gray, dark-brown stains.	2	7	3	4B	25 by 10 by 2
1,100	2 gray, brown stains.	3	7	2A	4A	25 by 10 by 1
1,200	1 brown	5A	7	B	4A	25 by 9.5 by 2 (warped)
SLIGHTLY STAINED MUSCOVITE, MADRAS, INDIA						
Normal	3 greenish gray	1	3	1	1A	25 by 10 by 0.4
600	4 greenish gray	1	3	1	1A	25 by 10 by 0.4
700	5 gray	2	6	3	2A	25 by 10 by 2
800	5 brownish gray	3	7	3	3B	25 by 10 by 1
900	4 grayish brown	3	7	4	3C	25 by 10 by 2
1,000	3 brown	3	7	3	3C	25 by 10 by 1.8
1,100	4 gray	3	7	2	4A	25 by 10 by 0.7
1,200	do.	6B	7	B	4A	22 by 9 by 1 (warped)
SLIGHTLY STAINED MUSCOVITE, BRAZIL						
Normal	2 gray	1	3	1	1A	25 by 10 by 0.2
600	1 gray	1	2	1	1A	25 by 10 by 0.2
700	4 gray	1	5	1	1A	25 by 10 by 0.2
800	6 gray	2	6	2	2C	25 by 10 by 1
900	6 brownish gray	2	7	3	3C	25 by 10 by 1
1,000	3 brown	3	6	3	3C	25 by 10 by 1
1,100	2 gray	5	6	2A	4A	25 by 10 by 0.7
1,200	1 gray	6B	7	B	4A	20 by 10 by 1.5 (warped)

TABLE 16.- Results of heating micas to elevated temperatures - Continued

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
GOOD STAINED MUSCOVITE, INDIA						
Normal	3 pinkish gray	1	3	1	1A	25 by 10 by 0.2
600	1 gray	1	2	1	1A	25 by 10 by 0.2
700	2 gray, brown stains.	2	5	1	1A	25 by 10 by 0.2
800	5 gray	3	7	3	3C	25 by 10 by 2
900	4 gray	2	7	3	3C	25 by 10 by 1.5
1,000	1 gray, brown stains.	2	6	3	3B	25 by 10 by 1
1,100	1 gray, brown stains.	3	7	3	4B	25 by 10 by 0.6
1,200	1 gray, brown stains.	5	7	B	4A	25 by 10 by 0.3
LIGHT-GRAY PHLOGOPITE, CANADA						
Normal	4 gray	2	5	1	1A	25 by 10 by 0.2
600	do.	2	5	1	1A	25 by 10 by 0.2
700	do.	2	5	1	1A	25 by 10 by 0.2
800	do.	2	5	1	1A	25 by 10 by 0.2
900	do.	2	5	1	2A	25 by 10 by 0.2
1,000	do.	2	6	2	2A	25 by 10 by 0.2
1,100	3 gray	3	7	2	3B	25 by 10 by 0.2
1,200	1 brown	6D	7	2	4A	25 by 10 by 0.5
DARK-GRAY PHLOGOPITE, LUCKY RESERVE MINE, QUEBEC, CANADA						
Not heated.	5 gray	2	6	1	2B	25 by 10 by 0.2
600	do.	2	6	1	2B	25 by 10 by 0.2
700	do.	2	6	1	2B	25 by 10 by 0.2
800	do.	2	6	1	2B	25 by 10 by 0.2
900	do.	2	6	2	2A	25 by 10 by 0.3
1,000	5 brownish gray	2	6	2	2A	25 by 10 by 0.7
1,100	3 brownish gray	3	7	2	3B	25 by 10 by 0.7
1,200	3 brown	5D	7	2	4C	25 by 10 by 0.8
DARK-GRAY PHLOGOPITE, CLIFF MINE, QUEBEC, CANADA						
Normal	6 gray	2	6	1	1A	25 by 10 by 0.3
600	5 gray	2	7	4	2C	25 by 10 by 2.5
700	do.	2	7	4	2B	25 by 10 by 1.5
800	5 brownish gray	2	7	4	3C	25 by 10 by 1.5
900	3 brown	2	7	4	3C	25 by 10 by 2
1,000	do.	2A	7	4	3D	25 by 10 by 3
1,100	2 brown	3C	7	4	3D	25 by 10 by 3
1,200	1 brown	5D	7	4A	4D	25 by 10 by 2.5

TABLE 16.- Results of heating micas to elevated temperatures - Continued

SOFT PHLOGOPITE, MADAGASCAR

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal	5 gray	3	4	1	3B	25 by 10 by 0.2
600	do.	3	4	1	3B	25 by 10 by 0.2
700	do.	3	4	1	3B	25 by 10 by 0.2
800	do.	3	4	1	3B	25 by 10 by 0.2
900	5 brownish gray	3	5	1	3B	25 by 10 by 0.2
1,000	5 brown	3	5	2	3B	25 by 10 by 0.5
1,100	5 brownish gray	3	6	2	3B	25 by 10 by 0.5
1,200	1 brown	6D	7	2	4C	25 by 10 by 0.5

MEDIUM SOFT PHLOGOPITE, MADAGASCAR

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal	5 gray	3	6	1	3A	25 by 10 by 0.4
600	do.	3	6	2	3B	25 by 10 by 0.6
700	do.	3	6	2	3C	25 by 10 by 0.6
800	do.	3	7	3	3C	25 by 10 by 1
900	do.	3	7	3	3C	25 by 10 by 1
1,000	do.	3	7	4	3C	25 by 10 by 2
1,100	3 brownish gray	3C	7	4	3D	25 by 10 by 2.5
1,200	3 brown	5D	7	4	4C	25 by 10 by 1.5

MEDIUM HARD PHLOGOPITE, MADAGASCAR

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal	7 gray	2	6	1	3A	25 by 10 by 0.4
600	5 gray	2	6	1	3A	25 by 10 by 0.4
700	do.	2	6	1	3A	25 by 10 by 0.4
800	do.	2	6	2	3A	25 by 10 by 0.7
900	do.	2	7	3	3C	25 by 10 by 2
1,000	5 brownish gray	3	7	4	3C	25 by 10 by 2
1,100	3 brownish gray	3	7	4	4B	25 by 10 by 1.5
1,200	3 brown	5D	7	4	4C	25 by 10 by 2

HARD PHLOGOPITE, MADAGASCAR

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal	Black	1	6	1	2A	25 by 10 by 0.3
600	do.	1	6	1	2A	25 by 10 by 0.3
700	do.	1	6	1	2A	25 by 10 by 0.3
800	do.	1	6	2	2A	25 by 10 by 0.8
900	6 brown	2	7	3	3B	25 by 10 by 1
1,000	do.	2	7	3	3C	25 by 10 by 1
1,100	4 brown	2	7	3	3D	25 by 10 by 1
1,200	3 brown	4D	7	2	4D	25 by 10 by 0.4

TABLE 16.- Results of heating micas to elevated temperatures - Continued

BIOTITE, SOUTH DAKOTA

Temperature, °C.	Color	Condition of surface	Opacity	Separation of laminae	Texture	Size, millimeters
Normal	7 brown	1	6	1	1A	25 by 10 by 0.4
600	do.	2BD	7	5	3C	25 by 10 by 4
700	6 brown	3	7	3	3B	25 by 10 by 2
800	do.	2B	7	3	3C	25 by 10 by 2
900	do.	3	7	3	3C	25 by 10 by 2
1,000	5 brown	3	7	3	3B	25 by 10 by 1.5
1,100	do.	5	7	B	4B	25 by 10 by 2
1,200	6 brown	6	7	B	4A	21 by 8.5 by 1.5 (warped)

There was no perceptible change in the micas after heating at 600° C. except that the biotite swelled to 10 times its original thickness and the phlogopite from the Cliff Mine, Quebec, Canada, swelled to about 8 times its original thickness. At 700° C. the three samples of Indian mica became opaque, and the Madras mica swelled notably. At this temperature 2 of the domestic muscovites, 1 from the Hibbs quarry in Maine and 1 from the Climax mine in South Dakota, remained transparent and were apparently unaffected. Four of the domestic muscovites lost their transparency at 700° C.; with the exception of the mica from Avon, Idaho, none changed as much as the Indian samples. At 700° C. both the muscovites from Guatemala and Brazil became opaque but did not swell. The Canadian phlogopite, affected at 600° C., showed further physical changes at 700° C. At 800° C. all muscovite samples showed radical changes, most of them swelling considerably. Two of the Canadian and all of the Madagascan phlogopites were not notably affected at this temperature. The best Canadian phlogopites and the soft Madagascan phlogopite withstood 1,100° C. without much apparent change except a lightening in color, but at 1,200° C. all the micas blistered and were so changed as to be unsuitable for use. It is interesting to note that the Guatemala muscovite, which is commonly thought to be unfit for heating elements, stood 600° C. without any apparent change and at 700° C. was no more affected than the best grades of Indian muscovite. At 1,200° C., however, it fused and contracted to one quarter of its original size.

Table 17 lists the micas in the order of their ability to withstand temperatures of 700°, 900°, and 1,100° C., respectively, according to the average grading of four independent observers who utilized a point system. A low score indicates excellent resistance and a high score, great physical changes; the best micas therefore are listed at the top of the columns. In grading the micas at a given temperature no attention was paid to the stages through which they had previously passed; that is, if a sample showed undesirable characteristics at 700°C. and seemed to have lost them at 900° C. it was graded at 900° C. solely on its characteristics after being subjected to this temperature.

It should be remembered that the order of arrangement in this table was determined by tests in which the specimens were under no external stresses; should conditions be altered in this respect the position of the micas in the tables might be changed considerably. For example, if one of the micas whose laminae separated considerably but whose other qualities remained desirable were placed under pressure it is possible that the mica would change places with one whose other properties were not as desirable.

TABLE 17.- Apparent order in which various micas are able to withstand elevated temperatures

Temperature, 700° C.

	Kind of mica	Points
1.	Phlogopite, light, Canada	16
2.	Muscovite, Abernathy mine, N.C.	17
3.	Phlogopite, hard, Madagascar	19
4.	Phlogopite, soft, Madagascar	20
5.	Phlogopite, medium hard, Madagascar	22
6.	Muscovite, Climax mine, S.Dak.	24
7.	Phlogopite, dark, Lucky Reserve mine, Canada	25
8.	Muscovite, Alexandria mine, N.H.	27
9.	Muscovite, good-stained, Indian	24
10.	Muscovite, Hibbs quarry, Maine	37
11.	Phlogopite, medium soft, Madagascar	40
12.	Muscovite, clear, Indian	43
13.	Muscovite, slightly stained, Brazil	44
14.	Muscovite, Sylvan Lake, S.Dak.	47
15.	Muscovite, Quatemala	61
16.	Muscovite, Avon, Idaho	62
17.	Phlogopite, Cliff mine, Canada	69
18.	Muscovite, Madras, India	72
19.	Biotite, South Dakota	74

Temperature, 900° C.

	Kind of mica	Points
1.	Phlogopite, light, Canada	6
2.	Phlogopite, soft, Madagascar	7
3.	Phlogopite, dark, Lucky Reserve mine, Canada	13
4.	Muscovite, Alexandria mine, N.H.	20
5.	Phlogopite, hard, Madagascar	21
6.	Phlogopite, medium soft, Madagascar	22
7.	Muscovite, good-stained, Indian	27
8.	Phlogopite, medium hard, Madagascar	32
9.	Muscovite, slightly stained, Brazil	33
10.	Muscovite, Avon, Idaho	38
11.	Muscovite, Hibbs quarry, Maine	47
12.	Muscovite, Climax mine, S.Dak.	55
13.	Muscovite, clear, Indian	56
14.	Muscovite, Sylvan Lake, S.Dak.	57
15.	Muscovite, Madras, India	58
16.	Biotite, South Dakota	60
17.	Muscovite, Guatemala	65
18.	Muscovite, Abernathy mine, N.C.	66
19.	Phlogopite, Cliff mine, Canada	75

TABLE 17.- Apparent order in which various micas are able to withstand elevated temperatures - Continued

Temperature, 1,100° C.

	Kind of mica	Points
1.	Phlogopite, soft, Madagascar	6
2.	Phlogopite, light, Canada	15
3.	Phlogopite, hard, Madagascar	16
4.	Muscovite, Madras, India	24
5.	Muscovite, Alexandria mine, N.H.	25
6.	Muscovite, Hibbs quarry, Me.	25
7.	Phlogopite, dark, Lucky Reserve mine, Canada	28
8.	Muscovite, good-stained, Indian	31
9.	Muscovite, Sylvan Lake, S.Dak.	32
10.	Phlogopite, medium hard, Madagascar	40
11.	Muscovite, Avon, Idaho	41
12.	Muscovite, Climax mine, S.Dak.	42
13.	Muscovite, Abernathy mine, N.C.	51
14.	Muscovite, clear, Indian	54
15.	Muscovite, slightly stained, Brazil	54
16.	Phlogopite, medium soft, Madagascar	57
17.	Phlogopite, Cliff mine, Canada	67
18.	Biotite, South Dakota	73
19.	Muscovite, Guatemala	74

The results of these heating tests distinctly favor domestic muscovites compared with the Indian muscovites and conclusively disprove statements to the effect that the Indian product has a higher resistance to heat. They also show the marked superiority of the soft, light-colored phlogopites over muscovites in heat resistance and suggest the use of these phlogopites where temperatures exceed 600° C.

GENERAL CONCLUSIONS

In conclusion, the tests made by the National Bureau of Standards show no notable differences in any of the more important physical properties of domestic and foreign micas. Their dielectric strength, change on heating, and power factors are virtually identical; other properties, such as flexibility and hardness, may be duplicated in comparable grades. To what, then, must the preference for Indian mica by many consumers be attributed? The answer is: To the more careful preparation and better grading of the Indian product. This is its only legitimate claim to superiority, but commercially it is the key to its dominance of the world market. Although some consumers think that Indian mica is inherently superior to all other micas, the Indian producers are under no such misapprehension. G. V. Hobson, an Enlishman who advises Indian producers on the marketing and utilization of mica, writes as follows in the Bulletin of Indian Industries and Labour, 1928:

> The demand frequently made by consumers for Indian mica only is often based not on any intrinsic superiority of Indian mica over that from other countries but on the more satisfactory grading and marketing of the product *** other countries are now alive to these facts, and the Indian producer must not, because of

the commanding hold India has on the market, be led to relax his efforts; instead, he should by constant attempts improve the condition in which his product is marketed so as to offset the growing competition from other countries.

Moreover, many large consumers in this country are aware of the good quality of our domestic micas.

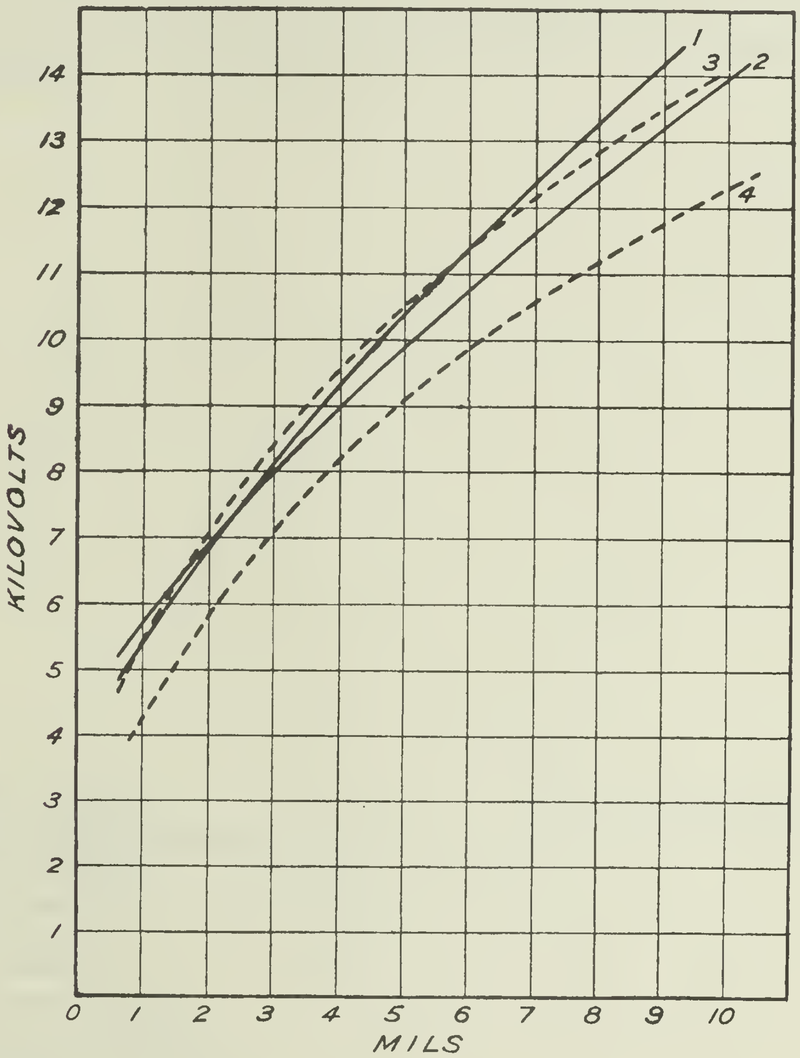

Figure 9.—Average dielectric strengths of four groups of muscovite specimens: 1, Domestic clear ruby mica; 2, domestic stained ruby mica containing air bubbles; 3, Indian clear ruby mica; 4, Indian stained ruby mica containing air bubbles.

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MINING METHODS AND COSTS AT THE MINE OF THE ST. JOSEPH LEAD CO., ATLANTA, IDAHO

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E. D. GARDNER

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MINING METHODS AND COSTS AT THE MINE OF THE ST. JOSEPH LEAD CO., ATLANTA, IDAHO[1]

By E. D. Gardner[2]

INTRODUCTION

This paper is one of a series on mining methods and costs being published by the United States Bureau of Mines.

In April 1934 the St. Joseph Lead Co., at Atlanta, Elmore County, Idaho, was mining and milling about 225 tons of gold ore daily with a total force of 150 men. The mine, which comprises the old Boise-Rochester and Monarch properties, is at an elevation of about 6,000 feet. Snow lies on the ground about 5 months each year but does not interfere greatly with local operations. However, the road to Mountain Home, the shipping point 80 miles distant, passes over a high range and usually is closed by snow from about November 15 to June 15. Heavy supplies are brought in and concentrates trucked out during the summer. In winter the district is served by a biweekly mail plane and a passenger and express plane making 4 to 6 trips weekly. Mine timber is cut locally. A plentiful supply of water is obtained from a stream brought to the property through 7,500 feet of plume.

ACKNOWLEDGMENTS

The information in this paper was supplied by F. W. Skeels, general manager, Atlanta division, St. Joseph Lead Co., and Wm. Thorsen, mine superintendent.

HISTORY

Atlanta is one of the early mining districts in Idaho. Mining operations have been carried on intermittently since ore was discovered in 1864. At one time Atlanta was one of the principal districts in the State; many millions of dollars in gold and silver have been produced in the district. The property now held by the St. Joseph Lead Co. was worked last in 1917 before this company entered the field.

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6823."

2/ Supervising engineer, U. S. Bureau of Mines Southwest Experiment Station, Tucson, Ariz.

The Boise-Rochester mine, which is now being operated, was opened by early operators with two drifts from the surface. The ore was taken to an amalgamation and gravity-concentration mill by an aerial tramway. The present company built a new amalgamation and flotation mill and ran a crosscut haulage level to the lode at the level of the mill 300 feet below the old workings. The company began operations on the ground August 18, 1931; the air compressor was started November 16, 1931 and the mill, February 1, 1932.

The development of flotation for gold ores during recent years has made possible a much higher recovery of gold and silver than was possible in the old amalgamation and gravity-concentration mill. Ores now can be mined that could not be worked profitably under the old conditions.

The St. Joseph Lead Co. was the largest producer of gold in Idaho in 1933; about 28.5 percent of the total production of the State was from this mine.

GEOLOGY

The ore occurs in the Atlanta lode; this is a shear zone 50 to 120 feet wide, at or near a contact of two granites of different ages. The lode is confined wholly to the older rock and has well-defined walls. The material in the shear zone is fractured and partly decomposed granite with minor quantities of quartz and calcite.

The ore occurs as lenses ranging from 4 inches to 40 feet wide and up to 360 feet long on the strike; the principal ore shoot has been followed for 600 feet on the dip. The orebodies occur on the footwall, near the hanging wall, or within the lode. The dip of the orebody being worked in May 1934 was 72° to 85°.

The ore consists of dark-colored quartz containing disseminated fine crystals of arsenopyrite, pyrite, and argentite. Pyrite which is generally barren is abundant in places. The gold occurs free and with the sulphides. The ore as it went to the mill in the spring of 1934 ranged from 0.3 to 0.5 ounce of gold and 0.75 to 3.00 ounces of silver per ton; the quartz streaks, however, were much higher in grade. There is no line of demarcation between the ore and the other lode material; in most places close sampling and assaying are necessary to determine the ore limits.

The ground within the lode although dry is very heavy and swells upon exposure to the air. Permanent openings within the lode are held open with difficulty; haulage drifts are run in the hanging wall. Close filling is required in the stopes. When a cut of ore is taken in a stope there is a tendency for blocks of vein material parallel to the ore to push into the opening.

The vein is prospected by running crosscuts every 100 feet from the drifts in the hanging wall. Seams of dark-colored quartz are followed by drifting and raising. Occasionally these seams widen out into orebodies. All new faces are sampled.

MINE EQUIPMENT

A completely new surface plant including buildings was constructed by the present company.

As the quantity of ore developed did not indicate a long life for the mine, equipment (except the power plant) was moved in from other properties of the company that were temporarily idle because of the low prices of base metals.

The mine equipment consists of the following: One 970-cubic-foot, 20-drill, two-stage, 19- by 11- by 14-inch Ingersoll-Rand XRE air compressor, driven by a direct-connected, 175-hp. motor running at 257 r.p.m.; two 1 1/2-ton Mancha storage-battery locomotives; one 20-kva generator for charging batteries; 4 extra batteries; forty 17-cubic-foot, 0.9-ton mine cars; 1 no. 50 Ingersoll-Rand drill sharpener; 15 to 20 Ingersoll-Rand CC stopers; 4 drifters; 7 jackhammers; and hand and miscellaneous tools.

Power Plant

Power for the mine, mill, and camp site is supplied mainly by a 360-hp., 8-cylinder, German-submarine, Diesel engine, direct-connected to a three-phase, 480-volt, 375 kva generator. A hydroelectric plant that generates from 40 to 125 hp., depending upon the water supply, is situated about 2 1/2 miles from the mine. The power from the two sources is synchronized at the Diesel plant.

DEVELOPMENT

The mine is developed by a haulage adit on the 900 level and a working adit on the 600 level. The main production of ore is from about the 600 level. Drifts are run midway between the main levels for prospecting and stoping the ore. The ore is drawn from chutes on the 600 level and trammed to a transfer raise to the 900 level, whence it is taken to the mill. The men enter the mine on the 600 level and are hoisted to the upper levels; the steel-sharpening and blacksmith shop, at which 200 pieces of steel are sharpened daily, is on this level. Supplies for the mine are taken by motor through the 600 level and hoisted through a vertical raise, extending 400 feet from the 600 to the 250 level.

Raises

Development raises are 3 feet 6 inches by 7 feet outside measurement; they are divided in the middle to make two compartments. Raise sets are placed on 5-foot centers. The raise timbers are framed in a shed equipped with planer, and cut-off, and band saws.

Raise rounds consist of an average of twelve 5-foot holes. The raises are run for a contract price of $4 per foot for labor and explosives. The company furnishes compressed air, timber, and other supplies and hauls the

muck from the bottom of the raise. A raise crew usually consists of 3 men on each of 2 shifts; occasionally, however, 2 men on each of 2 shifts comprise a crew.

Drifts

Drifts are run 5 by 7 feet in section. Drift rounds in granite consist of an average of 12 holes that break about 5 feet. A downward toe-cut hole round is drilled.

Drilling and crosscutting in the spring of 1934 were done at a contract price of $5 per foot for labor and explosives. The contractors also laid the track and put in the air lines as a part of the contract. The broken rock was trammed by hand to a switch not over 600 feet away. A drift crew consisted of 1 driller on one shift and 2 shovelers on another.

Drift sets in the crosscuts are placed on 5-foot centers by company timbermen.

STOPING

A horizontal cut-and-fill is the principal method of stoping; in wide sections of the vein the stopes are square-setted. Square-set sections are 15 to 40 feet wide. Cuts in the cut-and-fill stopes are 3 to 4 1/2 feet high. These stopes are carried up the width of the ore where it is 4 feet or more in thickness. Where the ore is less than 4 feet thick it is first broken and removed, then enough waste is shot down to provide filling. The thickness of the ore ranges from 3 to 40 feet.

The ore is shot down on 2-inch plank floors and shoveled into the chutes. Coarse waste is sorted out of the ore by the shovelers. The floors are taken up before filling.

Drilling is done with stopers. In wide stopes vertical holes are drilled 3 1/2 feet apart in two rows also 3 1/2 feet apart. A round consists of 12 to 20 holes. In breaking narrow streaks of ore in hard ground the holes are drilled 1 foot apart and staggered; they are shot with one stick of 30-percent-strength gelatin to the foot of the hole.

As the stoping progresses upward the regular manway and chute raises are carried up the fill on 40-foot centers. They are built up 5 feet at a time. One compartment is used for an ore chute and the other for a manway and timber slide. Timber and other supplies are hoisted and lowered to the stopes through these raises by means of Little Tugger hoists. A hoist is sometimes set at the bottom of a raise and the sheave attached to a tripod or stull over the timber slide, and at other times the hoist is on a truck on the level above.

Side blocks of vein material that tend to fall in the stope are supported largely by waste filling that is run into the stope as soon as a cut is completed. In wide cut-and-fill stopes the back requires some auxiliary support

until the space is filled. Casual stulls, both from the filling to loose blocks in the back and between walls of the stope, are placed as required. The backs of narrow stopes stand well.

In wide, filled stopes filling is obtained from inclined waste raises run across the lode in each section midway between the chute raises. These raises are in effect channels or inclined shrinkage stopes across the shear zone. Most of the orebodies occur on the footwall; hence in these sections the raises are run toward the hanging wall. Where the ore is on the hanging wall the raises are run toward the footwall. Where the ore is over 7 feet wide an extra waste raise is run in each section. The waste is leveled in the stopes by hand. It is allowed to pile up in the raises and drawn as needed.

The waste raises have prospecting value. Any seams of dark-colored quartz are followed; occasionally orebodies are found in this manner. The waste workings do not appear to cause weight in the stopes. In narrow stopes enough waste is broken during stoping to provide the necessary filling. The mine was originally laid out in such a manner that development waste could rarely be used as filling; this condition, however, has been overcome. Now, raises are usually extended between levels ahead of stoping.

In long stopes some of the 46-foot sections between raises are of different heights; where this is the case dry walls are built with coarse waste at the end of the sections to retain the filling.

The ore from the different stopes is drawn in a predetermined proportion and mixed to keep the mill heads as uniform as practicable.

TRAMMING

Tramming on the 900 and 600 levels is done by two 1 1/2-ton, Mancha, storage-battery locomotives. An extra battery is used for each locomotive. The charging stations are at the portal of the adits. The motor-generator set is in the engine house.

An ore train consists of 9 side-dump cars which hold 0.9 ton each. The track gage is 18 inches; 16-pound rails are used on the 900 level and 12-pound ones on the 600 level. Tramming is done by hand on the intermediate levels.

VENTILATION

The mine is naturally ventilated; rock temperatures are relatively low. The two main adits are outcast during the winter. The workings are connected with a shaft at the other end of the mine. The air appears good in stopes where the only connections are to a level 325 feet below. Definite currents travel up some of the manways and down others; they are controlled by doors at various places on the 600 level.

LABOR

The wage scale is miners, $5.00; muckers, $4.50; and shift boss, $5.50. The average daily force for mine, mill, and surface in April 1934 was as follows:

Mine	105
Mill	18
Surface (shops, power house, teamsters, etc.)	19
Engineers and assayer	3
Office and warehouse	5
Total	150

COSTS

The cost of explosives at the mine is as follows:

30-percent-strength gelatin dynamite	per pound	$0.128
Fuse	per foot	.014
Caps	each	.0115

The amount and cost of development work in April 1934 is shown in table 1.

The drifts are 5 feet 4 inches wide at the cap by 6 feet 4 inches high in the clear. The raises have three compartments and are 4 feet 8 inches by 10 feet 8 inches in the clear. All drifts and raises are timbered with 8- by 8-inch timber on 5-foot centers; the timber costs $25 per 1,000 board-feet.

In 1932 the cost of drifts and crosscuts was $7.78 and that of two-compartment raises $8.19 per foot.

Stoping costs are shown in table 2 and total cost per ton in table 3. The tonnage produced per man-shift is shown in table 4.

TABLE 1. - Cost of development work in April 1934

	Drifts (138 feet)	Raises (184.3 feet)
Labor	$4.93	$4.50
Supplies	1.537	2.86
Power	.24	.21
Total direct cost ...	6.707	7.57

TABLE 2. - Stoping costs in April 1934[1]

(6,174 tons)

	Labor	Supplies	Power	Total
Drilling	$0.73	2/$0.308	$0.10	$1.138
Shoveling	.65	.005	....	.655
Timbering	.35	.304	....	.654
Haulage	.17	.035	.037	.242
Miscellaneous	.05	......	.006	.056
Supervision	.13	......	....	.13
Total	2.08	0.652	0.143	2.875

1/ Includes filling and waste raises; does not include manager, general superintendent, assayer, general office, engineering, warehouse, village expenses, or taxes.

2/ Drill supplies, $0.063; explosives, fuse, and caps, $0.245.

TABLE 3. - Total costs per ton in April 1934

Development	$0.272
Stoping and transportation	2.797
Overhead and miscellaneous	.763
Milling	1.336
Total	5.198

TABLE 4. - Output per man-shift in April 1934

	Tons per man-shift
Miners, stoping	7.86
Shovelers	8.11
Miscellaneous underground (4 shift bosses, track and pipe men, etc.)	9.32
Total underground	2.60
Total all men	1.55
	Pounds per ton
Explosives for stoping and filling	0.148

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UNITED STATES BUREAU OF MINES
John W. Finch, Director

INFORMATION CIRCULAR

MINING AND MILLING METHODS AT THE BIG JIM MINE, OATMAN, ARIZ.

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

MINING AND MILLING METHODS AT THE BIG JIM MINE, OATMAN, ARIZ.[1]

By C. H. Johnson[2]

INTRODUCTION

The Big Jim mine of the United Eastern Mining Co. is at Oatman, Mohave County, Ariz. Oatman is in the foothills on the western side of the Black Mountains, at an elevation of about 3,000 feet. It is on a paved highway about 30 miles west of Kingman, the principal distributing center for mining supplies in the district, and 25 miles from Topock, on the Colorado River. Both latter towns are stations on the Santa Fe Railroad; Oatman has no rail connection.

Mining conditions are typical of western Arizona; water is scarce, no mine timber is available locally, and the winters are mild and the summers hot. The supply of skilled labor is usually adequate, but in 1933-34 it was not more than sufficient for the restricted operations. Wages have been $4.00 to $4.50 for miners. Electric power was supplied from Kingman and cost about 2.6 cents per kilowatt-hour.

The Big Jim claim was located in 1908, but no serious work was done until about 1915 when a crosscut on the 400 level entered the Big Jim vein.[3] In 1917 the ground was purchased by the United Eastern Mining Co. In 1922 an aerial tramway was completed from the Big Jim shaft to the United Eastern mill, a distance of about 5,000 feet. From 1921 to 1924 when the United Eastern Mining Co. ceased operations, the Big Jim produced about 220,000 tons of ore with an average value per ton of about $17.25.[4]

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6824."

2/ Assistant mining engineer, U. S. Bureau of Mines Southwest Experiment Station, Tucson, Ariz.

3/ Ransome, F. L., Geology of the Oatman Gold District, Arizona: U. S. Geol. Survey Bull. 743, 1923, 58 pp.
Lausen, Carl, Geology and Ore Deposits of the Oatman and Katherine Districts, Arizona: Ariz. Bureau of Mines Bull. 131, 1931.

4/ Moore, R. W., Mining Methods and Records at the United Eastern Mine: Trans. Am. Inst. Min. and Met. Eng., vol. 76, 1928, p. 71

In 1932 Rae L. Johnston and Ray S. Witcher leased the Big Jim ground, having decided that certain blocks of ore, too low in grade to extract under the conditions and costs prevailing in former years, could now be mined profitably.

Johnston kindly gave permission for publication of this paper and supplied most of the data. The writer is likewise indebted to B. M. Reynolds, mill superintendent, for information regarding operations at the mill.

MINING

General

The Big Jim orebody was described by Moore[5] as a fissure vein in andesite, ranging from a solid quartz-calcite filling to a series of parallel stringers separated by andesite and of the following maximum dimensions: Height, 450 feet; length, 850 feet; thickness, 35 feet. The vein dipped 70° to 75°.

A three-compartment vertical shaft on the hanging-wall side of the vein was about 730 feet deep; the orebody was developed by five levels, the first level being above the top of the ore (which did not outcrop) and the seventh and lowest level being below the bottom of the commercial ore.

Shaft Repair

The main shaft had two cage compartments 5 feet long and 4 1/2 feet wide and a manway 4 feet long and 4 1/2 feet wide. The end and wall plates were 8- by 8-inch and the dividers 6- by 8-inch timber. The present operators found the shaft badly crushed by a cave extending from about 65 to 200 feet below the collar. At the latter point two faults converged, one dipping steeply toward the end and the other toward the side of the shaft. Some of the timbers had yielded, and subsidence had taken place along some fault planes which were well-lubricated by gouge and surface waters. The whole block had dropped about 16 feet; an opening of this height that extended 25 or 30 feet from the shaft, with a more or less flat back, was formed at the top of the block. At first an attempt was made to straighten and repair the shaft through the caved mass by using jacket sets and supporting the back of the open space by stulls resting on the broken material. It was impossible, however, to support the pressure that developed; hanger rods pulled large washers through the wall plates, and auxiliary supporting cables extending from the collar to the caved section were snapped. It was then decided to remove the caved material and to support the open ground by careful timbering. First, long stringers placed like bearer sets across the shaft were hung by cables from the surface and blocked down under the brow of the cave to support it and prevent any new falls of rock. Then it became necessary to timber with short stulls one of the fault zones whose crushed filling and gouge had slipped down into the cave; this open space was 30 or 40 feet high and 5

5/ Work cited: pp. 56-57.

to 20 feet wide. This done and the back well-trimmed and at least partly supported by timber, mucking was started. Crews of 4 men underground and 2 men on top, working for the most part 2, but at the last 3, shifts per day, mucked and hoisted 4,500 to 5,000 tons of broken, crushed, and caved rock in a 1-ton sinking bucket and installed 21 new shaft sets and 8 jacket sets. The latter were at the bottom of the cave, where they could be blocked to solid ground. There has been no further caving; the whole former danger zone is open, though closely and intricately stulled and blocked, and can be inspected and watched. In future surface water cannot accumulate and lead to weakening or slipping of the fractured block of ground. This is an instance of the unforeseen and unpredictable expenses that may attend the simplest mining undertakings.

The work was begun September 1 and finished December 15. Shaft-men were paid $5 and $6 per shift; about $1,000 worth of timber, in the form of shaft sets and stulls, was used; and the cost of distillate for the hoist was $400 to $500 monthly. The entire job cost between $9,000 and $10,000.

Surface Plant

After the shaft was repaired preparations were made to mine. The surface plant of the Big Jim was in fair order, and little work or expenses was incurred in putting it in condition for operation. A small, wooden ore bin was purchased and moved intact from a neighboring mine to load the ore into trucks. The compressor equipment comprised two Imperial type 10 (Ingersoll-Rand) machines, one 19 by 12 by 16 and the other 17 by 10 by 14, or 1,100 and 600 cubic feet in capacity, respectively. The smaller one, more suitable for the work contemplated, lacked a motor, and a 75-hp. Allis-Chalmers motor was brought from the United Eastern mill and installed. In place of the large double-drum hoist used in former production a Fairbanks-Morse, single-drum, 60-hp., distillate-burning hoist was used, capable of raising a 1-ton car on the cage 250 feet per minute. It consumed about 25 gallons of distillate per shift, costing 14 cents per gallon.

The blacksmith shop contained a coal-burning forge, a Sullivan drill sharpener, and the usual grinding wheel, drill press, anvil, and tools.

Underground Development

The chief underground preparation for mining was to extend a track on the 500 level through an old, empty shrinkage stope by setting stulls from wall to wall until a block of low-grade ore next to the boundary line of the property was reached. The vein here was 3 1/2 to 6 feet wide and had strong walls. The block of ore was mined from the 500 to the 300 level by the open-stope method; stulls were used to hold working platforms. This form of stoping made possible a prompt and economical supply of ore to the mill without preliminary development and without tying up any of the ore as broken reserve in shrinkage.

Later an extension of the orebody on the 600 level was developed and mined by underhand stoping. A raise was first put up to the level above and benching begun. As stoping progressed downward, a second and then a third raise are started at intervals of about 50 feet, so that by the time benching reached the 600 level at one raise the next raise had made connection to the level above.

Raises were driven 3 1/2 to 5 feet wide, according to the thickness of the ore, and 12 feet long in the vein. The length of the raise (12 feet) not only produced a fair tonnage of mill ore but also made possible the most effective pointing of the cut holes. The mixture of quartz and calcite in the vein made a "tough" but readily drilled ground which was exceedingly hard to break; the average length of a raise round was only 3 1/2 feet. The round comprised 28 to 30 holes with a center V-cut; it was drilled with stopers by two miners. The cut holes were loaded with 5 sticks each of 40-percent-strength gelatin dynamite and the other holes with 4 sticks; they were detonated with white, cotton-countered fuse and no. 8 caps. The joints between fuse and caps were painted with Celocap. Stemming was used in all holes, but only after a determined effort on the part of the mine superintendent to establish the practice; it was made of mill tailings rolled in thin paper and packed in powder boxes. The cartridges were dampened slightly before using.

When two raises were running, the miners drilled and blasted 1 day in one, and the timberman set stulls and placed staging in the other. Because of the delay involved and the need to continue a regular mill supply, chutes were not installed as promptly as usual; instead, the ore was allowed to fall into the drift and was shoveled off shoveling sheets into mine cars.

Wire-rope ladders were found convenient in the raises. They were made by the mine blacksmith of 1/2-inch wire rope and old 1/2-inch round iron; the latter was cut to proper lengths, the ends were heated and bent into the shape of a hook, then they were placed over the rope at the proper intervals and hammered fast. These ladders could readily be hung over two short pieces of steel set in holes drilled in the footwall; they withstood the wear and tear of blasting with little damage. The stulls used were salvaged from old stopes; the only expense was the labor cost of getting them out.

Approximately 1.4 man-shifts (underground), 21 pounds of powder, 75 feet of fuse and 10 caps were expended per foot of raise. The total of these items was about $10; to this must be added compressed air, steel, supervision, and a proportion of hoisting and general underground and surface expense. Segregated costs of three such raises, based on a total advance of 85 feet in April 1933, are shown in table 1.

Underhand Stoping

The conditions in the 600-level orebody were satisfactory for underhand stoping. No timbering was necessary, and relatively high tonnage was broken per man-shift. Stopes were started at the top of a raise by drilling down holes with jackhammers. A series of benches was then carried down to the 600

level. An essential precaution was to maintain a rill steep enough so that most of the ore would fall into the raise without shoveling; the natural tendency of the miners was to drill and blast the higher, more accessible benches first, thus burying the lower steps and flattening the slope so that the muck would not run by gravity. One miner in an underhand stope, drilling 15 to 20 holes per round each shift, broke 20 to 25 tons of ore.

Mine Costs

The following table gives the mine crew in April 1933.

Number	Classification	Wages per day
1	Foreman miner	$6.00
5	Miners	4.50
1	Timberman	4.50
3	Carmen	4.00
1	Hoist engineer	5.00
1	Blacksmith	5.00
1	Cage tender, topman	4.00

Only one shift (day) was worked. Thus 50 tons per day was mined by 10 men underground and 3 on the surface, excluding superintendence; that is, 5 tons was produced per man-shift underground, or about 3.7 tons for the entire force. Compensation insurance cost $7.25 per $100 of mine pay roll.

Some of the principal items of operating cost other than labor were as follows:

	Cost	
	Per day	Per ton
Electric power, 300 kw.-hr. per shift at $0.0267	$8.00	$0.16
Distillate for hoist, 25 gal. per shift at $0.14	3.50	.07
Explosives:		
Dynamite, 2 1/2 boxes (50 pounds) 40-percent Hercules gelatin per shift at $7.25 per box	18.15	.36
Caps, 50 per shift at $0.025 for no. 8 or $0.016 for no. 6	1.00	.02
Fuse, about 300 feet per shift at $0.008 per foot	2.40	.05

To this must be added numerous items of supplies, such as track, pipe, oil, grease, steel, tools, coke, drill repairs, and water (which was purchased from a company pumping in a nearby shaft). Timber was not yet an item in mining costs, although it would be shortly. That purchased for shaft repair cost $40 per 1,000 board-feet, including an $8 to $9 trucking charge from Kingman.

The above cost items were determined readily from an unusually good set of records that was kept at this mine compared to ones usually kept at properties of its size. Labor, explosives, and cars trammed were entered on three daily sheets which listed all the working places. A large monthly distribution sheet was carried for each working place and for each account, such as "Hoisting", "Sharpening", etc. The data from the daily sheets were transferred to the monthly sheets, and from the latter a monthly resume was prepared, such as that shown in table 1. No warehouse account was carried; supplies consumed were entered directly from the invoices to the monthly distribution sheets.

To the costs in the following statement for April 1933 (table 1), trucking to the mill must be added. The ore was hauled by a contractor who used a single 7-ton, dump-body truck. The distance to the mill was about 1 mile, over a good, but winding, dirt road with only one short, steep grade. The ore was loaded from a chute into the truck and dumped directly into the coarse-ore bin at the mill. The contract price, including truck, labor (one driver), and all supplies, was 30 cents per ton.

MILLING

General

The mill which was rented from a neighboring company, was an all-slime cyanide plant built in 1923 by the Telluride Mining, Milling, & Development Co. at a cost said to be approximately $108,000. Its rated capacity was 50 tons per 24 hours. It was operated in 1924 and 1925, since when it had been idle. However, little expense was required to put it in operating condition. No changes or additions were made in the flow sheet or in the equipment.

The flow sheet (fig. 1) comprised coarse crushing, fine grinding (one stage of each), a stage of thickening from which the pregnant solution was derived, three stages of agitation, then five stages of thickening which produced a finished tailing. The pregnant solution was clarified, then treated by the Merrill-Crowe precipitation process. The capacity of the plant as then operated was 45 to 50 tons per day; the maximum in any day had been about 60 tons.

The ore treated contained no sulphides. Except for silver, which occurred in a ratio of 1 part to 2 parts of gold, no valuable metal other than gold was present. The ore was hard and "tough"; it consisted of roughly equal proportions of quartz and calcite, with small amounts of andesite wall rock. The gold was in the quartz and was so finely disseminated that an unusually fine degree of grinding was necessary to liberate it sufficiently for cyanidation. The presence of considerable clayey material in some of the ore, added to the tendency of the calcite to form slimes, made the pulp difficult to settle; settling area was the limiting factor in the capacity of this mill.

TABLE 1. - Mining costs, Johnston and Witcher lease on Big Jim mine, April 1933
(1,457 tons mined)

Working place	Tons	Breaking		Tramming		Hoisting		Timbering		General underground	
		Total	Per ton	Total	Per ton	Total	Per ton	Total	Per ton	Total	Per ton
Breaking ore:											
501 R (overhand stope)	196	$393.91	$2.009	$32.00	$0.163	$54.31	$0.277	$16.14	$0.082	$72.52	$0.370
503 R (overhand stope)	192	102.16	.532	38.00	.198	53.13	.277	8.46	.044	37.98	.198
435 U (underhand stope)	138	125.08	.906	38.00	.275	38.28	.277	6.16	.045	27.65	.200
6 A (underhand stope)	270	324.14	1.200	50.00	.185	71.83	.266	31.01	.115	48.35	.179
506 U (underhand stope)	406	281.98	.694	62.00	.153	112.19	.276	17.46	.043	37.98	.093
Ore dump1/	96	106.16	1.106	......	......	......	......	......	......	......	......
Total	1,298	1,333.42	1.027	220.00	.169	329.74	.255	79.23	.061	224.48	.173
Development:											
607 R	65	207.73	3.196	6.00	.092	17.80	.274	14.38	.221	24.17	.372
601 R	105	462.86	4.408	40.00	.381	29.08	.276	16.14	.154	72.52	.691
606 R	85	213.77	2.515	20.00	.235	23.44	.275	5.38	.063	24.17	.284
Total	255	884.36	3.468	66.00	.259	70.32	.275	35.90	.141	120.86	.473
Total	1,457	2,217.79	1.522	286.00	.196	400.06	.275	115.13	.079	345.34	.237
Development costs above shown separately and computed by cost per foot	Feet	Total	Per foot	Total	Per foot	Total	Per foot	Total	Per foot	Total	Per foot
607 R	20	207.73	10.386	6.00	.300	17.80	.892	14.38	.719	24.17	1.208
601 R	45	462.86	10.285	40.00	.888	29.08	.646	16.14	.360	72.52	1.611
	20	213.77	10.688	20.00	1.000	23.44	1.173	5.38	.269	24.17	1.208
Total	85	884.36	10.404	66.00	.776	70.32	.827	35.90	.422	120.86	1.423

1/ Payment to lessees working shaft dump on "split-check" basis.

TABLE 1.- Mining costs, Johnston and Witcher lease on Big Jim mine, April 1933--Continued
(1,457 tons mined)

Working place	Tons	Steel sharpening		Compressed air		Drill steel, hose, oil		Total cost of mining	
		Total	Per ton	Total	Per ton	Total	Per ton	Total	Per ton
Breaking ore:									
501 R (overhand stope)	196	$44.64	$0.228	$43.40	$0.221	$14.18	$0.072	$671.10	$3.424
503 R (overhand stope)	192	23.38	.122	21.70	.113	7.43	.039	292.24	1.522
435 U (underhand stope)	138	17.00	.123	14.46	.105	5.40	.039	272.03	1.971
6 A (underhand stope)	270	29.76	.110	28.93	.107	9.47	.035	593.49	2.198
506 U (underhand stope)	406	23.38	.057	21.70	.053	7.43	.018	564.12	1.389
Ore dump[1]	96	......	......	......	......	......	......	106.16	1.106
Total	1,298	138.16	.106	130.19	.100	43.91	.034	2,499.14	1.925
Development:									
607 R	65	14.89	.229	14.46	.222	4.73	.073	304.16	4.679
601 R	105	44.64	.425	43.40	.413	14.18	.135	722.82	6.884
606 R	85	14.89	.175	14.46	.170	4.73	.056	320.84	3.757
Total	255	74.42	.292	72.32	.284	23.64	.093	1,347.82	5.285
Total	1,457	212.58	.146	202.51	.138	67.55	.047	3,846.96	2.640
Development costs above shown separately and computed by cost per foot	Feet	Total	Per foot	Total	Per foot	Total	Per foot	Total	Per foot
607 R	20	14.89	.744	14.46	.723	4.73	.236	304.16	15.208
601 R	45	44.64	.992	43.40	.964	14.18	.315	722.82	16.061
606 R	20	14.89	.745	14.46	.723	4.73	.236	320.84	16.042
Total	85	74.42	.876	72.32	.851	23.64	.278	1,347.82	15.857

1/ Payment to lessees working shaft dump on "split-check" basis.

Crushing and Grinding

The ore was dumped from the trucks over a steeply slanting grizzly formed of flat steel bars set on edge with 1-inch spacing. The fine material fell into a separate section of the coarse-ore bin. The oversize ran into a coarse-ore bin which had a capacity of 30 to 35 tons; it was built of wood and had a sloping bottom. From this bin the ore was drawn by gravity through a feed gate to the coarse crusher. The crusher product passed directly onto an inclined conveyor belt, 12 inches wide and about 200 feet long, which discharged into the fine-ore bin. The grizzly undersize was fed through a separate gate onto the lower end of the same belt and conveyed to the fine-ore bin when the crusher was not running. The crusher was belt driven by a 50-hp. electric motor. It was operated 4 to 6 hours each day shift, crushing at a rate of 11 to 12 tons per hour. The conveyor belt passed through a Merrick weightometer; the tonnage recorded by this machine was found to check very closely the tonnage estimated according to number of 1-ton mine cars trammed to the mine surface bin; the monthly discrepancy was usually less than 1 percent.

The conveyor discharged into the center of the square, wooden, flat-bottomed, fine-ore bin, which had a maximum capacity of 80 tons. A hand-operated sample cutter was installed at the head of the conveyor belt. From a center discharge gate in the bottom of the fine-ore bin an apron feeder delivered the ore to the ball mill.

The ball mill was a 6- by 4 1/2-foot Marcy mill with Williamson "mechanite" liners that were changed to standard Marcy liners about 1933. It was driven at 18 r.p.m. by a 75-hp. motor and operated in closed circuit with a Dorr duplex classifier. The classifier discharge was 82 to 85 percent minus 200-mesh; it was later changed to 80 to 82 percent. Ball consumption ranged from 2.5 to 4.5 pounds of chrome-steel balls per ton or ore; the mill run had been too short to determine liner consumption. The ball mill operated from 78 to 80 percent of the total time; grinding capacity was 2.5 tons per hour of operating time.

Grinding was done in cyanide solution, which was drawn from the main-mill storage tank at the rate of about 330 tons per 24 hours. A portion of this was added in the feed launder at the head of the mill; the balance was added at the lower end of the classifier. About 50 percent of the value recovered from the ore was dissolved in the mill.

Cyanide Section

The classifier overflow, having a dilution of 6 to 1 (or carrying 15 percent solids), flowed by gravity to the no. 1 thickener in the cyanide plant. This was a wood-stave tank 24 feet in diameter and 8 feet deep. It was equipped, as were all the thickeners and agitators, with a Dorr mechanism which was belt-driven through a long countershaft by a single 25-hp. motor. The thickener overflow passed by gravity to the precipitation section of the plant. The thickened discharge, containing about 40 percent solids, was raised by a diaphragm pump to the first of a series of three agitating tanks.

The tank of no. 1 agitator was 19 feet in diameter and 14 feet deep; nos. 2 and 3 agitators were 13 feet in diameter and 14 feet deep. The agitators were set at such relative elevations that the pulp flowed from one tank to the next by gravity. Air for the agitator air lifts, as well as for periodical drying of precipitate in the filter press, was furnished by a 7 1/2- by 6-inch compressor at a pressure of 30 pounds per square inch. The compressor was driven by a 10-hp. motor.

About 95 percent of the gold recovered was taken into solution by the time the pulp left no. 3 agitator. From there it went to no. 2 thickener, whence it was pumped in turn to thickeners 3, 4, 5, and 6. These thickeners were all 15 feet in diameter and 10 feet deep. They were set at such heights that the clear overflow from each ran by gravity to the next lower numbered tank. The thickened-pulp discharges contained about 50 percent solids. Fresh water was added to no. 6 thickener in the amount of 50 tons daily; the barren solution from the precipitation section, 180 tons daily, was added to the feed launder of no. 4 thickener. This solution contained about 2.2 pounds of sodium cyanide and 2.0 pounds of lime per ton, also a trace of gold. The overflow from no. 2 thickener, 330 tons per day, was pumped to the mill storage tanks. The thickened slime from no. 6 thickener flowed to the tailings dump. No solution was reclaimed from the tailings; they were allowed to run down the draw below the mill; within a short distance the water sank into the ground.

The overflow from no. 1 thickener ran by gravity into a Butters clarifying filter having a tank 11 feet in diameter and 5 1/2 feet deep; thence it was pumped into the clear gold-solution tank 11 feet in diameter and 6 feet deep. From this tank it passed through the standard Merrill-Crowe, vacuum-treatment, zinc-dust precipitation process. Zinc dust and lead acetate were added to an emulsifier ahead of the triplex circulating pump by an automatic feeder. The Merrill precipitate press was installed in a room adjacent to the grinding section of the mill about 200 feet from the pump.

Melting Precipitate

Usually the precipitate press was cleaned about twice monthly, after first blowing air through it for 3 to 4 hours to dry the precipitate. The precipitate was fluxed about as follows: Precipitate, 100 pounds; borax, 20 pounds; soda, 10 to 12 pounds; silica (broken glass), 6 pounds. This charge, together with some slag from the previous melt, was melted in an oil-fired tilting furnace. The fusion usually required 8 to 9 hours, including the time needed to put in and melt down the charge; the furnace consumed 25 or 30 gallons of fuel oil in this time. Compressed air for the oil burner was obtained from the compressor at the Telluride mine, where development work was in progress. The no. 150 Dixon graphite crucibles used had a life of about 40 hours, or 4 or 5 fusions. The entire charge was poured off into a cone-shaped mold; after a few minutes the slag was tapped off through a hole 2 or 3 inches above the top of the gold button and granulated by being run into water. At first this material was accumulated, periodically ground in a small mill, and concentrated on a table, the concentrates being added to a later precipitate melt. Afterward the low-grade slag was returned to the ball mill, as it was found to contain practically no shot gold. The richer slag from just above the top of the button contained most of the shot gold; it was melted with the succeeding charge.

The gold-silver button was cleaned and shipped to the mint without remelting; a sample was taken first by boring several small holes in it. The average fineness was 640 parts per 1,000 of gold, and 300 parts of silver, and 60 parts of base metal and impurities.

Metallurgical Results and Costs

The recovery was 97 to 98 percent. Cyanide consumption was 0.75 to 1.00 pound of sodium cyanide per ton of ore, and lime consumption was 3 3/4 to 4 pounds per ton. Zinc dust was added at the rate of 8 pounds per 24 hours, or 0.7 ounce per ton of solution, and lead acetate at the rate of 1 ounce per ton of ore.

The mill pay roll included 9 men: 1 superintendent whose time was charged to assaying and refining; 1 crusher man on day shift only; 1 man whose time was divided between assaying, refining, and general service; and 2 shift men, or operators, on each of three 8-hour shifts. Experienced men were paid $4.50 and ordinary labor $4.00.

Power cost $0.0267 per kilowatt-hour (May 1933). The total installed electric power in the mill was 200 hp., divided as follows:

Motor	Hp.
Crusher	50
Ball mill	75
Main conveyor	10
Apron feeder	5
Compressor	10
Cyanide plant	25
Pumps	25

However, the crusher operated only about 5 hours and only on day shift; the ball-mill motor was said to be operating at only about 70 percent full load. Consequently, the average total mill load was about 90 hp., and power consumption was about 30 kw.-hr. per ton.

Cyanide (Aero Brand sodium cyanide) cost $160 per ton (April 1933); lime cost $19 per ton, of which $5.50 was trucking cost from Kingman to Oatman; zinc cost $8 per 100 pounds; and the monthly water bill, for a daily consumption of about 50 tons, was about $100, or about 30 cents per 1,000 gallons.

The costs shown in the following regular monthly statement (table 2) are representative.

TABLE 2. - Milling cost, Johnston and Witcher lease on Big Jim mine, July 1933

(1,635 tons milled)

	Labor		Electric power		Water		Lime		Miscellaneous chemicals		Cyanide		Zinc	
	Total	Per ton	Total	Per ton	Total	Per ton	Total	Per ton	Total	Per ton	Total	Per ton	Total	Per ton
Assaying 1/ ..	$283.00	$0.173	$10.15	$0.006	.....	.....	......	.....	$20.11	$0.012	......	.....	.....	.....
Crushing	140.13	.086	30.43	.018	.....	.....	......	.....	.....	.....	......	.....	.....	.....
Grinding	393.88	.241	507.26	.310	.....	.....	......	.....	29.10	.018	......	.....	.....	.....
Cyaniding	425.19	.260	456.54	.279	$78.61	$0.048	$116.51	$0.071	4.91	.003	$172.62	$0.106	$32.00	$0.020
Repair and replacement..	....	.....	......	.....	.....	.....	......	.....	.....	.....	......	.....	.....	.....
Refining and marketing ...	31.50	.019	10.14	.006	.....	.....	......	.....	.....	.....	......	.....	.....	.....
Rental of mill	....	.....	......	.....	.....	.....	......	.....	.....	.....	......	.....	.....	.....
Total	1,273.70	.779	1,014.52	.620	78.61	.048	116.51	.071	54.12	.033	172.62	.106	32.00	.020

	Replacement and repair parts		Balls		Fuel oil and lubricants		Insurance and shipping		Mill rental and miscellaneous		Total cost of milling	
	Total	Per ton	Total	Per ton	Total	Per ton	Total	Per ton	Total	Per ton	Total	Per ton
Assaying 1/ ..	.....	.....	......	.....	$9.93	$0.006	.....	.....	....	.....	$323.25	$0.197
Crushing	.....	.....	......	.....	.....	.....	.....	.....	....	.....	170.56	.104
Grinding	$58.25	$0.036	$130.77	$0.080	2.02	.001	.....	.....	....	.....	1,121.28	.686
Cyaniding	19.92	.012	......	.....	4.50	.003	.....	.....	....	.....	1,310.80	.802
Repair and replacement..	.....	.....	......	.....	.....	.....	.....	.....	....	.....	....	.....
Refining and marketing ...	.....	.....	......	.....	10.05	.006	$8.64	$0.005	....	.....	60.33	.036
Rental of mill	.....	.....	......	.....	.....	.....	.....	.....	$1,000.00	$0.612	1,000.00	.612
Total	78.17	.048	130.77	.080	26.56	.016	8.64	.005	1,000.00	.612	3,986.22	2.437

1/ Cost of assaying includes cost of superintendence.

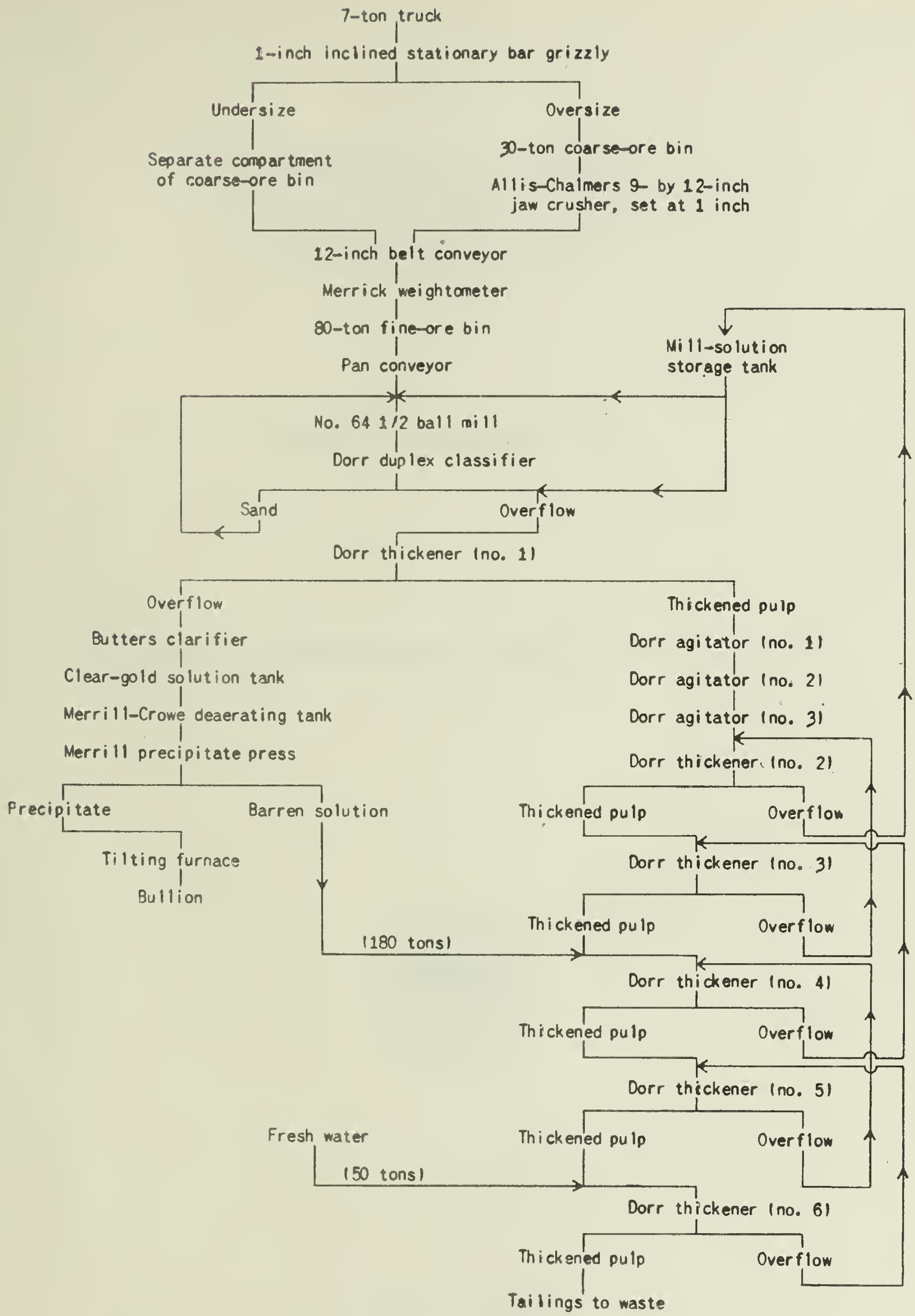

Figure 1.- Flow sheet of Big Jim (Telluride) mill.

I. C. 6825

March 1935

DEPARTMENT OF THE INTERIOR

UNITED STATES BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

SUMMARY OF DRIFTING AND CROSSCUTTING COST DATA

BY

CHAS. F. JACKSON

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I.C. 6825
March 1935

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SUMMARY OF DRIFTING AND CROSSCUTTING COST DATA[1/]

By Chas. F. Jackson[2/]

INTRODUCTION

This paper is a tabular compilation of data contained in a series of information circulars dealing with mining methods and costs at a large number of mines in the United States and some foreign countries. These circulars have been published from time to time during the years 1929 to 1934 inclusive.

From time to time, as enough data became available in these circulars, other circulars and bulletins have been published in which the data bearing upon different phases of mine operation were summarized, discussed, and analyzed. The present paper is a compilation of data on costs of drifting and crosscutting contained in earlier circulars, designed to assemble this information in a convenient form for reference without attempting lengthy discussion of details of drifting and crosscutting practice. For such details the reader is referred to the circulars on individual mines.

Because of the number of headings required to present the most pertinent contributory information, it has been necessary to separate the tables into two parts, one covering this information and the other the cost data. The name of each mine is preceded by a reference number in the first part which is repeated in the second part for easy correlation of the data. Figures 1 to 17, taken from earlier information circulars, illustrate methods at a number of the mines cited.

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6825."
2/ Principal mining engineer, U. S. Bureau of Mines.

TABLE 1. - Costs in dollars; part 1, contributory information

Mine	Reference Inf. Circ.	Kind of rock	Rock size of heading, feet	Round drilled: No. of holes	Round drilled: Type	Drilling machines	Shoveling; hand or mechanical	Timbering
1. Mineville, N.Y.	6092	Gneiss	15 x 10	28	Fig. 1	2, heavy Leyner	Power shovel	None
2. Tri-State No. 1	6113	Chert and limestone	7 x 7	12	Fig. 2	1, heavy Leyner	Hand	None
3. Tri-State No. 2	6121	do	7 x 7	12	4-hole pyramid cut	do	do	None
4. Barr	6159	do	7 x 7	14	Fig. 3	1, medium weight Leyner	do	None
5. S. E. Missouri, Mine No. 8	6160	Limestone	7 x 8	16	Fig. 4	Jackhammer	do	None
6. Mascot	6239	Dolomitic limestone	7 x 7 and 8 x 8	20	Fig. 5	---	do	None
7. Hanover-Bessemer	6361	Limestone, granodiorite, iron ore	8 x 7 to 9 x 8	?	Center cut	Leyners	do	Partly timbered, regular drift sets
8. Spring-Hill	6402	Limestone and diorite	7 x 7	12	Fig. 6	Heavy Leyner	do	None usually
9. Granada	6709	Hard graywacke, conglomerate and vein material	5 x 7	18	4-hole pyramid cut	do	do	None
10. Teziutlan	6736	Metamorphosed igneous and sedimentary rocks, and ore	6 x 8	17	-	2, heavy Leyners	do	10% in waste, 50% in ore
11. Park-Utah Main tunnel	6290	Limestone and quartzite principally	8 x 8	-	-	2, Leyners	do	1/3 timbered
12. Bunker Hill & Sullivan	6407	Quartzite	7 x 8	14	Fig. 7	---	Hand	Timbered

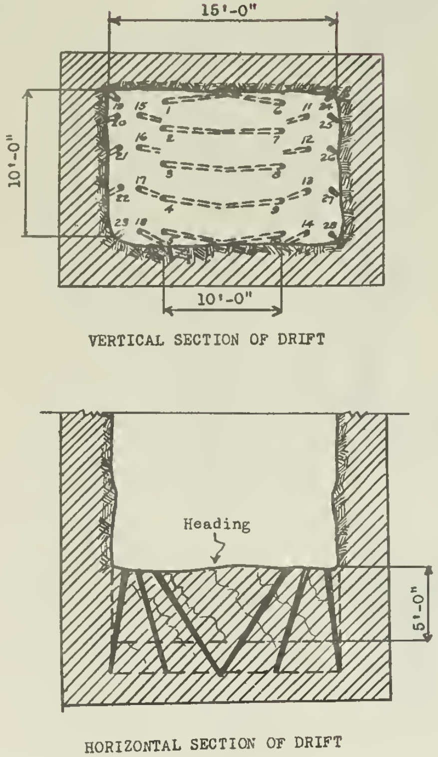
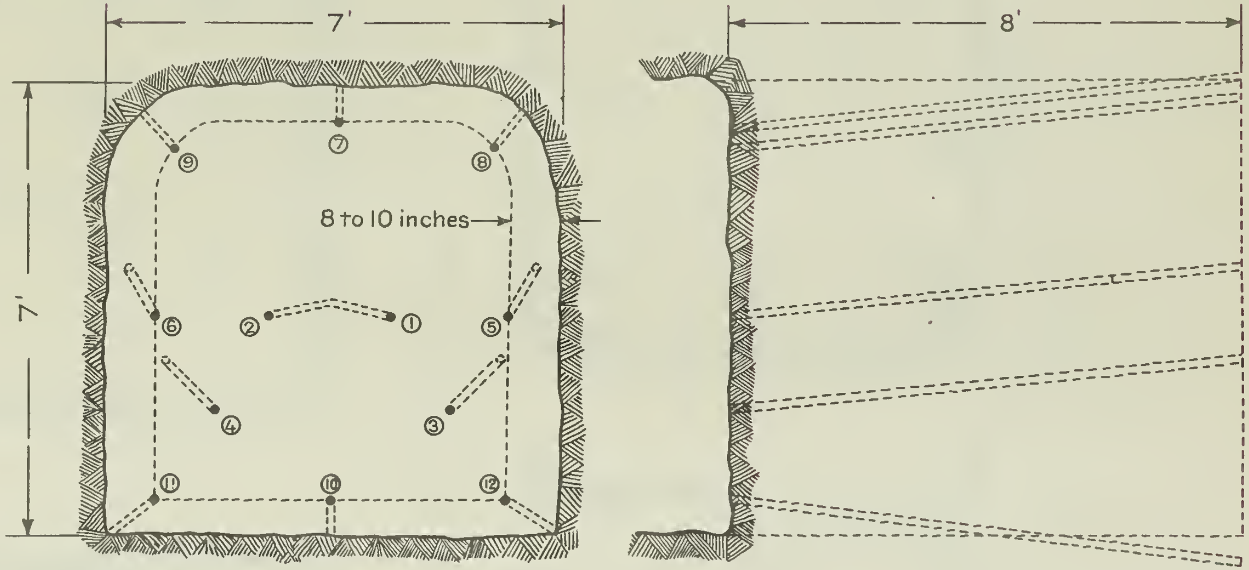


Figure 1.— Mineville, N. Y.
(I. C. 6092).



Order of firing "pull drift" round			
First	1 2	6 ft. deep	20 to 30 sticks 35 % gelatin
Second	3 4	8 " "	15 " 20 " " "
Third	6 6	8 " "	10 " " "
Fourth	7 then 8 9	8 " "	10 " " "
Fifth	10 then 11 12	8 " "	12 to 15 " " "

Figure 2.— Tri-State No. 1 (I. C. 6113).

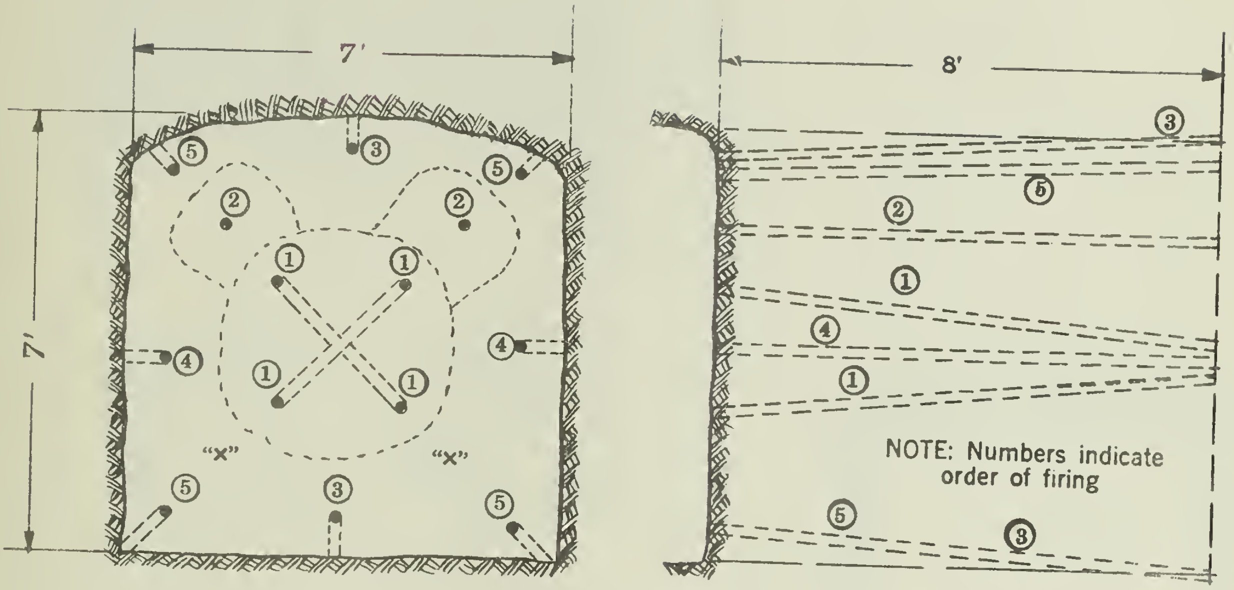


Figure 3.– Barr mine (I. C. 6159).

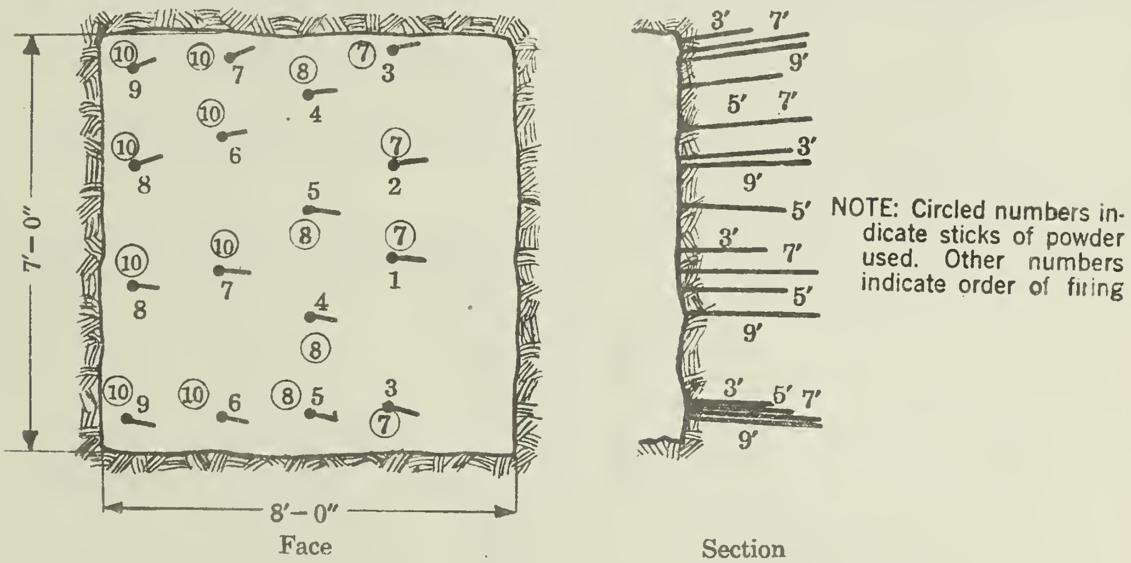


Figure 4.– S. E. Missouri, Mine No. 8 (I. C. 6160).

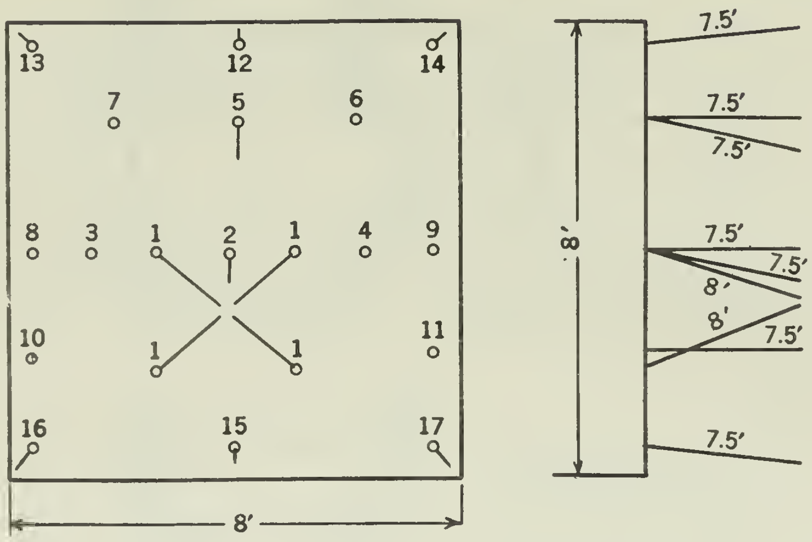


Figure 5.– Mascot, Tenn. (I. C. 6239).

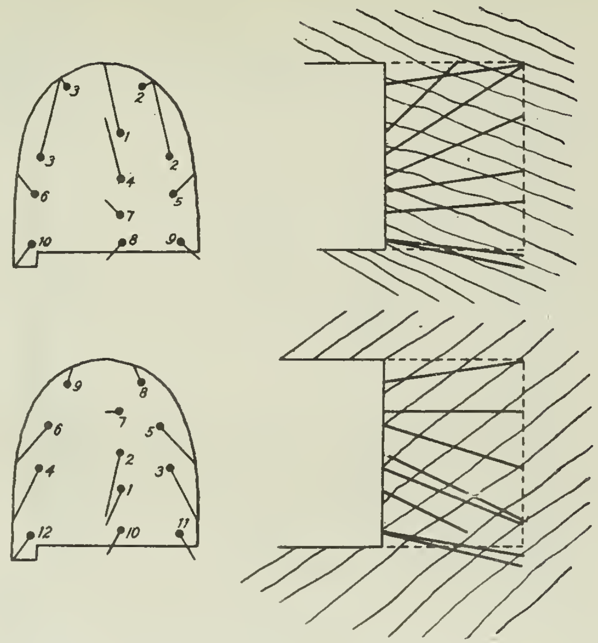


Figure 6.– Drift rounds, Spring Hill mine. Cut-holes cross jointing (I. C. 6402).

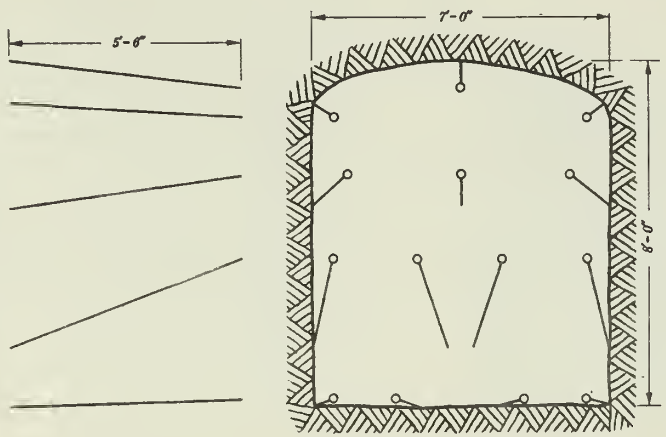
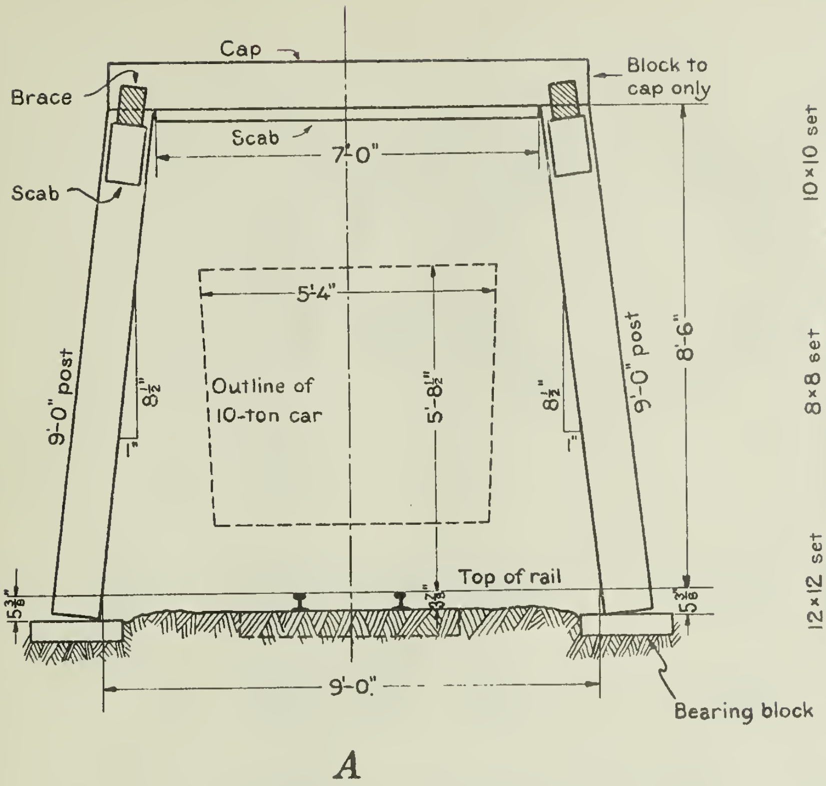


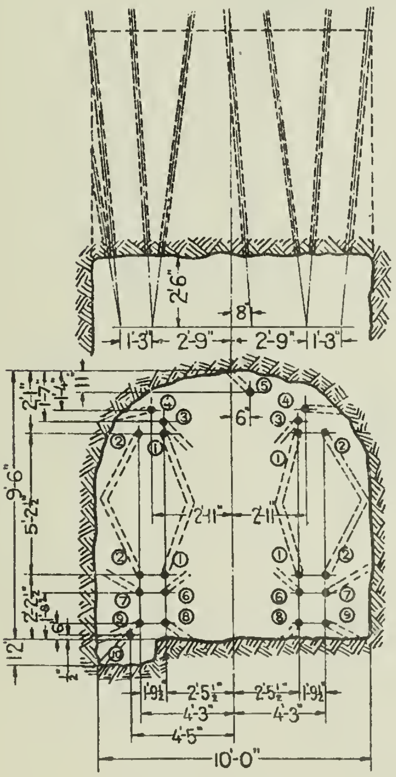
Figure 7.– Bunker Hill and Sullivan mine (I. C. 6407).



Set	No. of pieces	Pieces	No.	Description	Bo. ft.
		LIST OF TIMBER FOR 1 SET			
10×10 set	2	Posts	39	10x10x9-0 Batter 1 End As Shown	150.0
	1	Cap	42	10x10x8-8 Sq Ends	72.2
	1	Scab	128	2x10x7-0 " "	11.7
	2	Scabs	44	2x8x1-0 " "	2.7
	2	Braces	63	6x8x4-2 " "	33.3
	2	Bearing Blocks	45	4x12x1-8 " "	13.3
				TOTAL BOARD FT.	283.2
8×8 set	2	Posts	46	8x8x9-0 Batter 1 End As Shown	96.0
	1	Cap	49	8x8x8-4 Sq. Ends	44.3
	1	Scab	11	2x8x7-0 " "	9.3
	2	Scabs	44	2x8x1-0 " "	2.7
	2	Braces	62	6x8x4-4 " "	34.6
	2	Bearing Blocks	45	4x12x1-8 " "	13.3
				TOTAL BOARD FT.	200.2
12×12 set	2	Posts	52	12x12x9-0 Batter 1 End As Shown	216.0
	1	Cap	55	12x12x9-0 Sq. Ends	108.0
	1	Scab	27	2x12x7-0 " "	14.0
	2	Scabs	44	2x8x1-0 " "	2.7
	2	Braces	61	6x8x4-0 " "	32.0
	2	Bearing Blocks	45	4x12x1-8 " "	13.3
				TOTAL BOARD FT.	386.0

Blasting chart

Holes	Order of firing	Kind of powder and amount per hole					
1	First						
2	Second						
3	Third						
4	Fourth						
5	Fifth						
6	Sixth						
7	Seventh						
8	Eighth						
9	Ninth						
10	Tenth						



183 feet of drilling

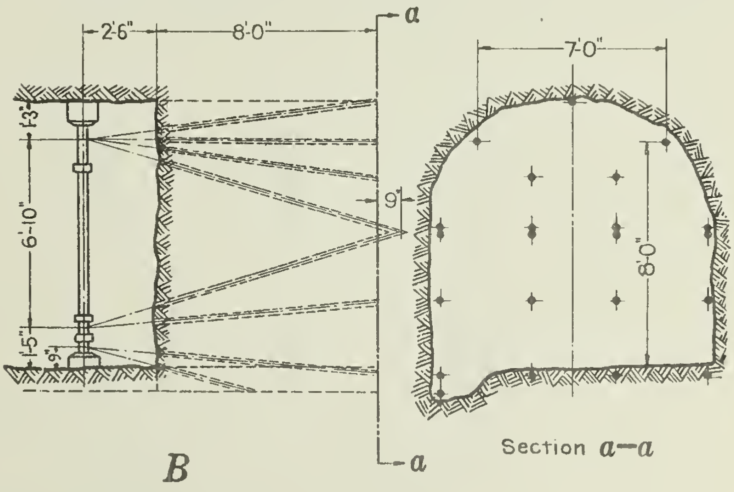


Figure 8.—Morenci (I. C. 6107): *A*, Fifth level, standard drift set; *B*, standard 8-foot round, 9½ by 10 foot drift.

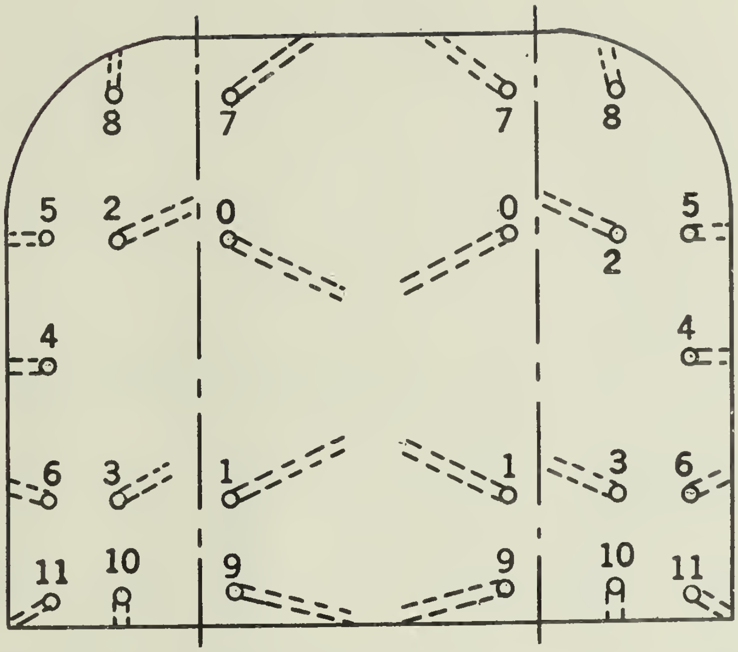


Figure 9.— Rock drift round 9′×11′, Eureka–Asteroid mine (I. C. 6348).

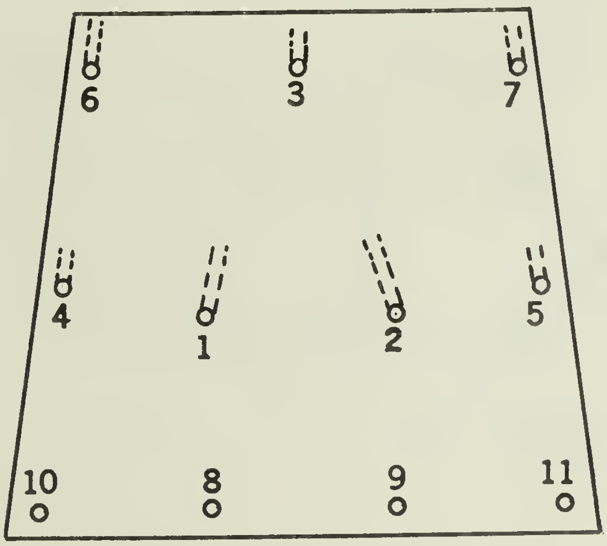


Figure 10.— Sublevel ore drift round 8′×9′, Eureka–Asteroid mine (I. C. 6348).

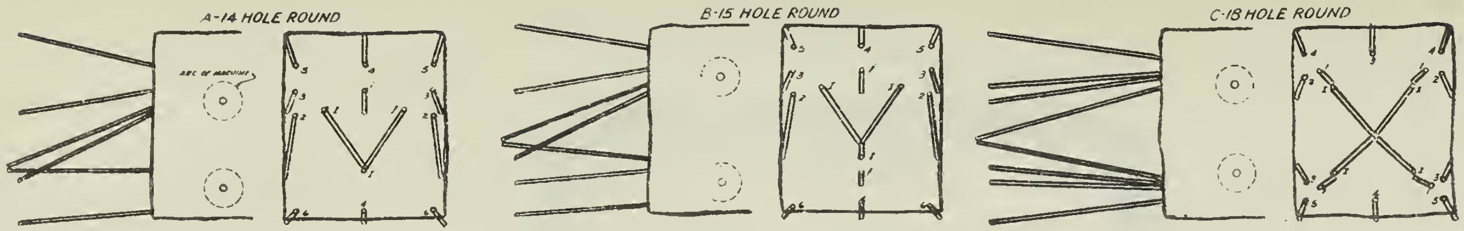


Figure 11.— Engels mine (I. C. 6260).

NOTE: Circled numbers
indicate order of firing

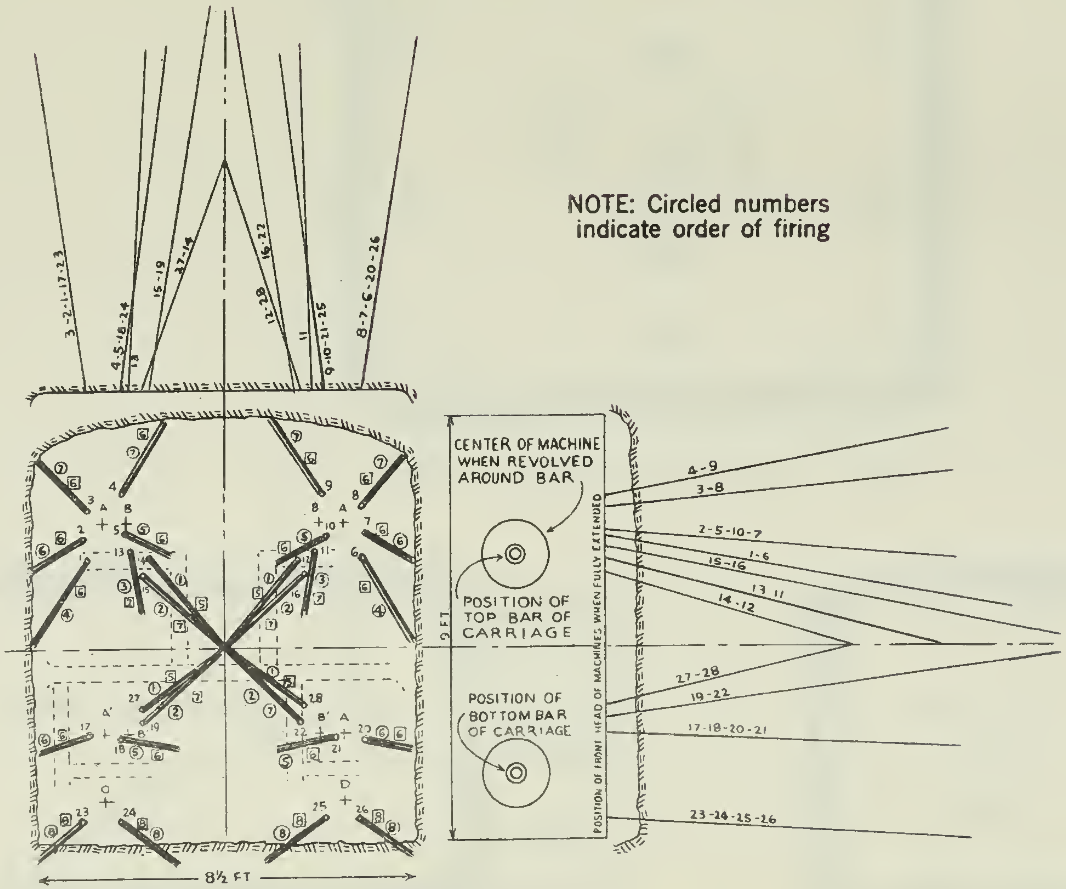


Figure 12.— Ojvela tunnel (I. C. 6480).

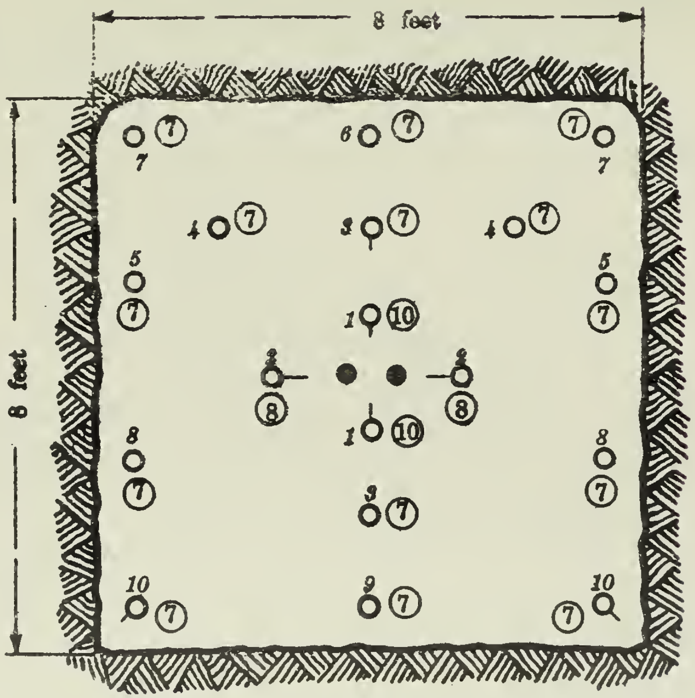


Figure 13.– Burra-Burra mine (I. C. 6149).

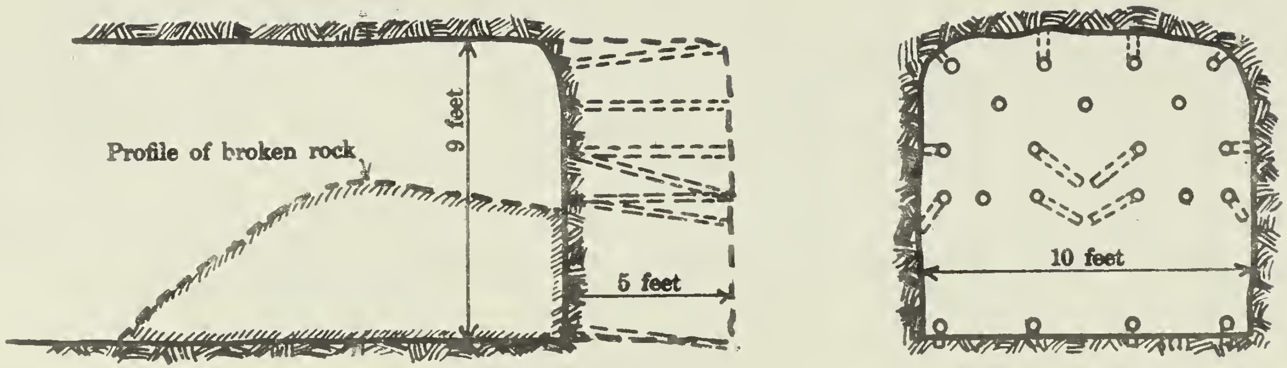


Figure 14.– Rock drift round, Marquette Mine No. 2 (I. C. 6179).

TABLE 1. - Costs in dollars; part 1, contributory information--Continued

Mine	Reference-Inf. Circ.	Kind of rock	Rock size of heading, feet	Round drilled: No. of holes	Round drilled: Type	Drilling machines	Shoveling; hand or mechanical	Timbering
13. Pecos	6368	Granitic schist and vein material	7 x 8	12-16	Toe-cut	Leyner	Hand	Timbered
14. Questa	6514	Porphyry	4½ x 6½	7-8	do	Light drifter	do	-
15. Morenci	6107	do						
1. Grizzly drifts			4 x 6			-	do	None
2. Supply drifts			6 x 8			-	do	None
3. Motor drifts, untimbered			8 x 9			2 Leyners	Power shovel	do
4. Motor drifts, timbered			10 x 10	21	Fig. 8	do	do	Fig. 8
16. Ray	6167	Quartz-sericite schist, some porphyry						
1. Grizzly drifts			4 x 5	-	-	-	Hand	Untimbered
2. Supply drifts			6 x 8	-	-	-	do	Timbered
3. Haulage drifts			8½ x 9	13-15	V-cut	Leyners	do	do
17. Eureka Asteroid	6348	Iron formation, slate, chert, quartzite						
1. Main level, untimbered			8 x 10	24	Fig. 9	4 Leyners in rock, jackhammer augers in ore	Power scrapers	Round-timber sets in ore
2. Main level, timbered			9 x 11	-	-		do	
3. Sublevel, timbered			8 x 9	11	Fig. 10			
18. Alaska-Juneau	6186	Gabbro and medium-hard slate						
1. Gold Creek Tunnel			9 x 7	-	Pyramid cut	Medium-weight Leyner	-	Untimbered
2. Main haulage			9 x 9		do	do	-	do
3. Drifts and crosscuts			7 x 5		do	do	-	do
4. Powder drifts			4 x 3		-	-	-	do
19. Engels	6260	Tough diorite and altered diorite	6 x 7	14-18	Fig. 11	Medium-weight Leyner	Hand	do

TABLE 1. - Costs in dollars; part 1, contributory information--Continued

Mine	Reference-Inf. circ.	Kind of rock	Rock size of heading, feet	Round drilled: No. of holes	Round drilled: Type	Drilling machines	Shoveling; hand or mechanical	Timbering
20. Eighty-five	6413	Vein matter, diorite, andesite, porphyry	5 to $6\frac{1}{2}$x7	13-22	V-cut	Light Leyner	Hand	Untimbered
21. Verde Central	6464	Vein matter, greenstone, quartz porphyry; hard	5 x 7	---	---	Medium-weight drifters	do	do
22. Elkoro	6543	Vein matter and volcanic flows	5 x 7	12-16	Down-cut	Light drifters	do	Timbered with round timber
23. Ojuela	6480	Limestone and calcareous shales	8 x $9\frac{1}{2}$	28	Fig. 12	4 heavy drifters on drill carriage	Power shovel	Untimbered, except near portal
24. Central Patricia	6681							
1. Drifts		Quartz veins	5 x 7	---	---	Medium-weight Leyner	Hand	Untimbered
2. Crosscuts		Greenstone	5 x 7	---	---	do	do	Mostly untimbered
25. Ashley	6707	Quartz vein and basalt	Drifts 5 x 7 Crosscuts 6 x 7	---	---	do	do	Untimbered

TABLE 1. - Costs in dollars; part 2, costs per foot of advance

Mine	Year	Wage rates: Base for drillers	Wage rates: Contract price average per foot	Costs per foot of advance: Labor	Comp. air, drills, and steel	Explo-sives	Timber	Track	Miscel-laneous	Total	Rate of advance, feet
1. Mineville	1927	$ 2.88	?	$ 9.90	$ 1.80 1/	$ 2.36	0.0	2/	$ 1.40	$ 15.46	5 per shift
2. Tri-State No. 1	1928	4.25	$ 7.50	7.37	1.38	2.38	.0	.46	2.54	14.13	6 per round
3. Tri-State No. 2	1928	do	9.00	-	-	-	-	-	-	-	7 per round
4. Barr	1928	4.75	6.00	-	-	-	-	-	-	10.00 to 12.00	do
5. S.E. Missouri, Mine No. 8	1928	5.05		4.89	3/ 1.13	-	-	-	4/ 1.85	7.87	3 to 6
6. Mascot	1929	-	-	4.07	1.57	2.25	-	-	.28	8.17	6.5
7. Hanover-Bessemer	1929	-	-	6.13	2.41	2.05	.83	.44	.18	12.04	-
8. Spring Hill	1930	5.50	6.00	-	-	-	-	-	-	-	5 1/2 to 6
9. Granada	1932	5.54	-	6.01	3/ .96	2.89	-	-	-	-	3.4 per 8-hour shift
10. Texiutlan	1930-31	-	-	8.83	2.01	2.50	.82	-	3.30	17.46	-
11. Park-Utah	-	-	-	16.09	2.01	2.44	.28	1.48	1.54	23.84	-
12. Bunker-Hill & Sullivan	1928	-	-	5.01	1.17	2.41	.46	-	2.38	11.43	-
13. Pecos	1927-29, inc.	$ 4.50	5.00 untimbered 8.50 timbered	8.08			All supplies		3.22	11.30	-
14. Questa	1930										
1. Machine drilling				3.79	1.93	1.25	.14	.30	-	7.41	4 per round
2. Hand drilling				5.47	-	.70	.14	.15	-	6.46	
15. Morenci	1928										
1. Grizzly drifts		-	-	3.78	1.38	1.10	1.63	-	1.12	9.01	-
2. Supply drifts		-	-	5.67	1.38	1.15	2.20	-	1.27	11.67	-
3. & 4. Haulage drifts		-	-	6.76	1.38	1.42	1.99	-	1.88	13.43	-

TABLE 1. - Costs in dollars; part 2, costs per foot of advance--Continued

Mine	Year	Wage rates		Cost per foot of advance							Rate of advance, feet
		Base for drillers	Contract price average per foot	Labor	Comp. air, drills and steel	Explosives	Timber	Track	Miscellaneous	Total	
16. Ray	1928										
1. Grizzly drifts		-	-	$ 2.22	5/$ .58	$ .66	-	-	.19	$3.65	-
2. Supply drifts		-	-	4.46	5/ .88	.74	$1.93	-	.28	8.29	-
3. Haulage drifts		-	-	7.43	5/ 1.54	.95	4.37	-	.50	14.79	5 per round
17. Eureka-Asteroid	1929	$ 4.64									Up to 924 feet per month
1. Main level, untimbered			$ 6.00	-	-	-	-	-	-	-	
2. Main level, timbered			6.50	-	-	-	-	-	-	-	
3. Sublevel, timbered			$2.50-$3.00	-	-	-	-	-	-	-	
18. Alaska-Juneau											
1. Gold Creek Tunnel	1911-1913	-	-	-	-	-	-	-	-	20.49	-
2. Main haulage	1928	5.50	12.50-14.50								
3. Drifts and crosscuts	do	5.50	7.00-8.00								
4. Powder drifts	do	5.50	5.50-6.50								
19. Engels	1929	5.00	9.00	-	-	-	-	-	-	13.09	-
20. Eighty-five	1928-29										
1. -1465 Crosscut		4.02	-	4.29	2.50	1.83	-	-	-	8.62	-
2. West drift 1650 level		-	-	5.98	2.75	2.38	-	-	-	11.11	
21. Verde-Central	1927	5.69	-	6.19	2.26	2.71	-	-	.54	11.70	4 per round
22. Elkoro	1930	-	-	6.577	1.328	2.094	.018	-	.286	10.303	-
23. Ojuela Tunnel	1927-28			6/10.33	3.48	3.77	-	-	7/3.785	21.365	714 per month

TABLE 1.-- Costs in dollars; part 2, costs per foot of advance--Continued

Mine	Year	Wage rates		Cost per foot of advance							Rate of advance, feet
		Base for drillers	Contract price average per foot	Labor	Comp. air, drills and steel	Explo- sives	Timber	Track	Miscel- laneous	Total	
24. Central Patricia	1930										
1. Drifts		-	-	$ 6.21	$ 4.36	$ 3.50	-	.37	.34	8/$14.78	-
2. Crosscuts		-	-	6.57	4.52	3.54	.02	.64	.36	9/ 15.65	-
25. Ashley 10/	1932	-	-	6.24	11/ 6.11	2.91	-	1.05	.75	12/ 17.06	-

1/ Includes track.
2/ Included under compressed air, drills, and steel.
3/ Power only.
4/ Includes explosives.
5/ Machine drills only.
6/ Includes rock disposal, $0.32; ventilation $0.36; and general, $2.67.
7/ Includes power, $0.84.
8/ Adding hoisting, loading and dumping, sampling and assaying, pumping, operation of mine dry, and proportion of overhead charges, the total cost was $21.23. This was purely a development operation.
9/ Adding same items as above, total cost was $24.09.
10/ Purely a development operation.
11/ Rock drills, accessories, and drill parts, $1.70; drill steel, $0.60; pipe and fittings, $1.03; steel sharpening, $0.69; boiler fuel and power, $2.09.
12/ Adding decking and surface tramming, hoisting and fuel, general underground and surface labor, salaries and office expense, the total becomes $22.54.

TABLE 2. - Costs in man-hours per foot; part 1, contributory information

Mine	Reference-Inf. Circ.	Kind of rock	Rock size of heading, feet	Round drilled: No. of holes	Round drilled: Type	Drilling machines	Shoveling, hand or mechanical	Timbering
8. Spring Hill	6402	Limestone and diorite	7 x 7	12	Fig. 6	Heavy Leyner	Hand	Usually none.
9. Granada	6709	Hard graywacke, conglomerate, and vein material	5 x 7	18	4-hole pyramid	do	do	do
10. Teziutlan	6736	Metamorphosed igneous and sedimentary rocks and ore	6 x 8	17	-	2 heavy Leyners	do	10% in waste, 50% in ore
13. Pecos	6368	Granitic schist and vein material	7 x 8	12-16	Toe-cut	Leyner	do	Timbered
15. Morenci	6107	Porphyry						
1. Grizzly drifts			4 x 6	-	-	-	Hand	None
2. Supply drifts			6 x 8	-	-	-	do	do
3. Motor drifts			8 x 9	-	-	2 Leyners	Power shovel	do
4. Motor drifts			10 x 10	-	-	do	do	Fig. 8
16. Ray	6167	Quartz-sericite schist, some porphyry						
1. Grizzly drifts			4 x 5	-	-	-	Hand	None
2. Supply drifts			6 x 8	-	-	-	do	Timbered
3. Motor drifts			$8\frac{1}{2}$ x 9	13-15	V-cut	Leyners	do	do
17. Eureka-Asteroid	6348	Iron formation, slate, chert, quartzite						
1. Main level			8 x 10	24	Fig. 9	4 Leyners in rock, jack-hammer augers in ore	Power scrapers	None
2. do			9 x 11	-	-	do	do	Timbered

TABLE 2. - Costs in man-hours per foot; part 1, contributory information--Continued

Mine	Reference-Inf. Circ.	Kind of rock	Rock size of heading, feet	Round drilled: No. of holes	Round drilled: Type	Drilling machines	Shoveling, hand or mechanical	Timbering
22. Elkoro	6543	Vein matter and volcanic flows	5 x 7	12-16	Down-cut	Light drifters	Hand	Timbered
23. Ojuela	6480	Limestone and calcareous shales	8 x 9½	28	Fig. 12	4 heavy drifters on drill carriage	Power shovel	Untimbered, except near portal
26. Burra-Burra	6149	Metamorphosed graywacke; congoomerate, schist, and massive sulphide ore	8 x 8	20	Fig. 13	Medium-weight Leyners	Hand	Untimbered
			4 x 6 (sublevel)	-	-	do	do	do
27. Marquette, No. 2	6179	Iron formation; chert, slate, and soft iron ore	10 x 10	21	Fig. 14	Medium-weight drifters	Power shovel	Timbered in ore, not in rock
28. Marquette, No. 4	6390	Slate, jasper, and moderately hard hematite	8 x 8 in rock	-	-	-	-	Untimbered
			10 x 10 in ore					Timbered
29. Morning	6238	Vein; galena and sphalerite in siderite, barite and quartz.	13 x 13 drifts	25-26	Fig. 15	2 drifters	Power shovel	Drift sets
		Quartzite	(6 x 8 Crosscuts	-	-	-	-	None
30. Champion	6515	Trap and amygdaloidal lava	8 x 13½	35	Fig. 16	2 medium-weight Leyners	Power scraper	Partly timbered

TABLE 2. - Costs in man-hours per foot; part 1, contributory information--Continued

Mine	Reference-Inf. Circ.	Kind of rock	Rock size of heading, feet	Round drilled: No. of holes	Round drilled: Type	Drilling machines	Shoveling, hand or mechanical	Timbering
31. Black Rock Drifts	6370	Granite; veins of sphalerite and galena in altered granite, quartz and pyrite	(7 x 9 (and (8 x 10 ((in ore)	12-15	Usually toe-cut	Leyners	Hand	Sill sets
Crosscuts			6 x 8	do	do	do	do	Untimbered
32. Page Drifts	6372	Soft, loose, swelling ground, veins in quartzite	8.5 x 9	16	do	Light drifters	do	Timbered
Crosscuts		Loose, broken quartzite	5 x 7	-	-	do	do	do
33. Montreal	6369	Iron ore, slate, chert, quartzite						
1. Main-level drifts and crosscuts in rock			9 x 9	15	Fig.17,A	2 light drifters	Power scrapers	Timbered
2. do			8 x 8	22	Fig.17,B	2 heavy drifters	do	Untimbered
3. Sublevel drifts and crosscuts in rock			7 x 7	-	-	do	do	do
4. Main-level drifts and crosscuts in ore			9 x 12	-	-	4 drifters	do	Timbered

TABLE 2. - Costs in man-hours; part 2, man-hours per foot of advance

Mine	Year	Man-hours per foot of advance: Drilling and blasting	Shoveling	Tramming and hoisting	Timbering	Super-vision	Miscel-laneous	Total	Advance per man-shift, feet
8. Spring Hill	1930	3.03	(3.03	- - - -)	-	-		6.06	1.32
9. Granada	1932	4.70	2.35	2.39	-	0.19		9.63	.83
10. Teziutlan	1930-31	7.73	14.77	12.17	1.44	1.87		37.98	.21
13. Pecos	1929	-	-	-	-	-		13.0	.62
15. Morenci	1928								
1. Grizzly drifts		-	-	-	-	-		2.84	2.81
2. Supply drifts		-	-	-	-	-		2.84	2.81
3. and 4. Motor drifts		-	-	-	-	-		8.16	.98
16. Ray	1928								
1. Grizzly drifts		-	-	-	-	-	-	3.70	2.16
2. Supply drifts		-	-	-	-	-	-	6.90	1.16
3. Motor drifts		-	-	-	-	-	-	9.52	.84
17. Eureka-Asteroid	1929								
1. Main level, untimbered		4.27	-	.82	.82	-	-	5.91	1.35
2. Main level, timbered		3.71	2.03	1.35	1.35	-	-	8.44	.95
22. Elkoro	1930	2.74	5.62	.18	.33	.32	-	9.19	.87
23. Ojuela	1927-28	9.32	2.76	7.45	-	-	1/9.03	2/28.56	.28
26. Burra-Burra	1928								
8x8 drifts		3.30	(3.30	- - - -)	-	-	-	6.60	1.21
4x6 drifts		3.30	(2.90	- - - -)	-	-	-	6.20	1.29
27. Marquette No. 2	1928	.83	2.00	1.33	.50	.08	-	4.74	1.69

TABLE 2. - Costs in man-hours; part 2, man-hours per foot of advance--Continued

Mine	Year	Man-hours per foot of advance							Advance per man-shift, feet
		Drilling and blasting	Shoveling	Tramming and hoisting	Timbering	Super-vision	Miscel-laneous	Total	
28. Marquette No. 4	1929	1.55	2.83	1.20	1.92	.22	-	7.72	1.04
29. Morning	1928								
Drifts (13x13)		-	-	-	-	-	-	28.80	.28
Crosscuts (6 x 8)		-	-	-	-	-	-	8.90	.90
30. Champion	1930	4.90	6.20	.80	1.20	1.10	-	14.20	.56
31. Black Rock	1929								
Drifts		-	-	-	-	-	-	9.6	.80
Crosscuts		-	-	-	-	-	-	7.5	1.07
32. Page	1928								
Drifts		-	-	-	-	-	-	4.8	1.67
Crosscuts		-	-	-	-	-	-	4.8	1.67
33. Montreal	1928								
1. 9 x 9 drifts and crosscuts		4.41	2.02	-	2.77	-	-	9.20	.87
2. 8 x 8 drifts and crosscuts		4.98	2.86	-	-	-	-	7.84	1.02
3. Sublevel drifts and crosscuts		6.79	2.50	-	-	-	-	9.29	.86
4. 9 x 12 drifts and crosscuts		3.94	1.09	-	2.21	-	-	7.24	1.10

1/ Ventilation, 1.24; miscellaneous, 7.79.
2/ Includes all labor on tunnel separate from regular mine operation and includes air compression, disposal of rock on surface, etc.

TABLE 3. - Explosives, timber, and power

Mine	Reference-Inf. Circ.	Rock size of heading, feet	Explosives per foot, pounds	Timber per foot	Power per foot, kw.-hr.			
					Air comp.	Haulage and hoisting	Ventilation	Total
8. Spring Hill	6402	7 x 7	9.40	None	-	-	-	46.0
9. Granada	6709	5 x 7	15.67	None	-	-	-	63.0
10. Teziutlan	6736	6 x 8	10.97	29.6 bd.ft.	190.4	53.0	8.0	251.4
11. Pecos	6368	7 x 8	9.40	16.4 lin.ft.	28.9	16.9	Misc. 0.5	46.3
15. Morenci	6107							
1. Grizzly drifts		4 x 6	5.94	None	-	-	-	-
2. Supply drifts		6 x 8	7.25	None	-	-	-	-
3. Motor drifts		8 x 9	11.95	None	-	-	-	-
4. do		10 x10	10.45	107.88	-	-	-	-
16. Ray	6167							
1. Grizzly drifts		4 x 5	4.84	None	-	-	-	-
2. Supply drifts		6 x 8	5.39	50 bd. ft.	-	-	-	-
3. Motor drifts		8½x 9	6.92	113 bd. ft.	-	-	-	-
17. Eureka-Asteroid	6348							
1. Main level		8 x 10	16.00	None	-	-	-	-
2. do		9 x 11	8.00	74 bd. ft.	-	-	-	-
22. Elkoro	6543	5 x 7	8.96	.440 lin.ft.	-	-	-	-
23. Ojuela	6480	8 x 9½	22.70	None	88.7	2.6	40.9	132.2
26. Burra-Burra	6149							
1. Main levels		8 x 8	11.2	None	-	-	-	36.0
2. Sublevels		4 x 6	9.5	None	-	-	-	30.0

TABLE 3. - Explosives, Timber and Power--Continued

Mine	Reference-Inf. Circ.	Rock size of heading, feet	Explosives per foot, pounds	Timber per foot	Power per foot, kw.-hr. Air Comp.	Haulage and hoisting	Ventilation	Total
27. Marquette No. 2	6179	10 x 10	25.5	-	-	-	-	-
28. Marquette No. 4	6390	8 x 8 and 10 x 10	20.2	-	-	-	-	-
29. Morning	6238							
1. Timbered drifts		13 x 13	20.0	149.1 bd.ft.	-	-	-	-
2. Untimbered crosscuts		6 x 8	11.3	6.9 bd.ft.	-	-	-	-
30. Champion	6515	8 x 13½	17.0	11.0 bd.ft.	-	-	-	-
31. Black Rock	6370							
1. Drifts		7 x 9 and 8 x 10	12.5	45.0 bd.ft.	-	-	-	-
2. Crosscuts		6 x 8	9.9	20.0 bd.ft.	-	-	-	-
32. Page	6372							
1. Drifts		8½ x 9	15.7	79.0 bd.ft.	-	-	-	-
2. Crosscuts		5 x 7	12.9	54.0 bd.ft.	-	-	-	-
33. Montreal	6369							
1. Main level		9 x 9	11.6	64.0 bd.ft.	-	-	-	-
2. do		8 x 8	12.9	None	-	-	-	-
3. Sublevel		7 x 7	8.1	None	-	-	-	-
4. Main level		9 x 12	7.4	89.0 bd.ft.	-	-	-	-

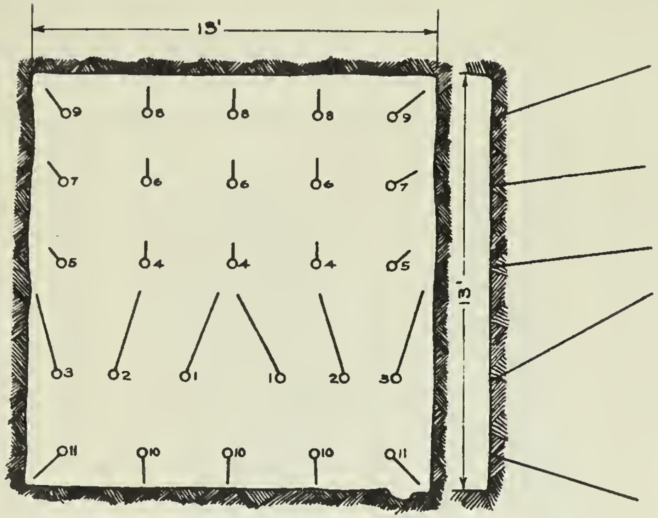


Figure 15.—Morning mine (I. C. 6238).

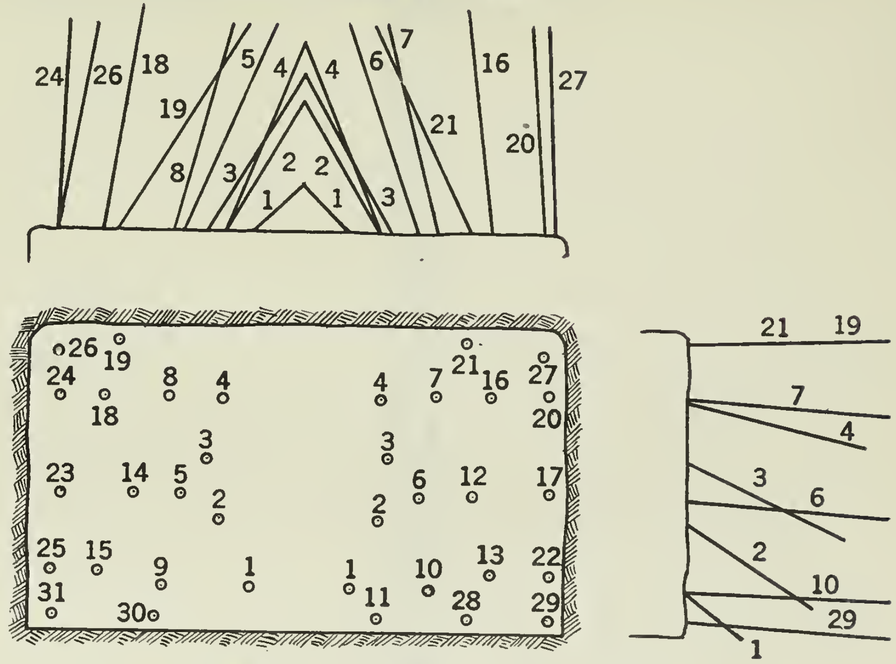


Figure 16.—Champion mine (I. C. 6515).

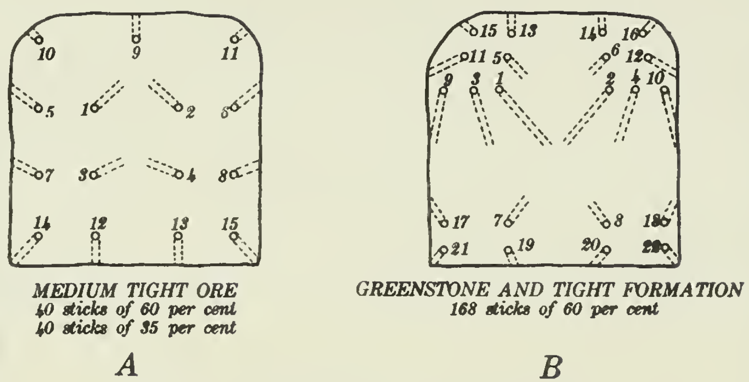


Figure 17.—Montreal mine (I. C. 6369).

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INFORMATION CIRCULAR

SAND AND GRAVEL EXCAVATION;

PART 3: HYDRAULIC DREDGE, CLAMSHELL DREDGE, LADDER DREDGE, AND DIPPER DREDGE

BY

J. R. Thoenen

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INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SAND AND GRAVEL EXCAVATION - PART 3:[1] HYDRAULIC DREDGE, CLAMSHELL DREDGE, LADDER DREDGE, AND DIPPER DREDGE

By J. R. Thoenen[2]

INTRODUCTION

This circular is part 3 of the third paper (entitled "Excavation") of a series summarizing the technical problems involved in the production and preparation of sand and gravel. Part 1 discussed the use of power shovels, draglines, and excavator cranes. Part 2 discussed the use of power scrapers, slackline cableway excavators, and hydraulic monitors. This circular discusses the use of the hydraulic, clamshell, ladder, and dipper dredge. Part 4 to follow will discuss the use of haulage equipment, and subsequent parts will discuss the application of both excavating and haulage equipment to various types of deposits.

HYDRAULIC DREDGE

Judged by the number of installations and the tonnage produced, as recorded in part 1 of this circular, the hydraulic or pump dredge is the most popular type of underwater sand and gravel excavator.

Considered as a complete unit, the hydraulic dredge is essentially individualistic in design and reflects a coordination of the requirements of local conditions, operators' desires, and manufacturers' experience. It has no standardization of design. Each dredge is built locally to suit local conditions. Therefore for the purpose of this circular the study of hydraulic dredges must be confined to discussion of the fundamentals governing their construction and operation.

In its simplest form the hydraulic dredge consists of a centrifugal pump and its driving mechanism, mounted on a wooden or steel hull floating on a natural or artificial body of water. (See figs. 7 and 8.) In this form the operation of the dredge may be limited to the excavation of gravel and its delivery to scows moored alongside. As such, it performs the function of an excavator only.

Without any material change in design, this same type of dredge may perform the function of transportation as well as excavation. The only alteration necessary is the extension of the pump-discharge line to the treatment plant on shore, thus eliminating conveyance by barges. Obviously the distance from dredge to plant will govern the scope of work devolving upon the pump.

Where the distance from dredge to plant is too great or presents sufficient difficulties to create a doubt as to the economic advantage of combining excavation and transportation duties in the pump, two alternatives are available to the operator. He can either design his dredge as an excavator only, or he can use a larger hull and install thereon machinery for wholly or partially treating the dredged product. Either alternative leaves the trans-

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portation function to a separate unit consisting usually of towboats and barges. The dredge in the former case reverts to the simplest design and performs the single function of excavation. In the latter case the dredge again performs two functions - excavation and treatment. In the simpler forms of this design the machinery added washes the dredged material and separates the sand from the gravel, discharging both to the transporting unit. The final sizing and preparation for market are done at the shore plant. In the more elaborate development the entire treatment plant is installed on the dredge, and finished products only are shipped from it to distribution or storage yards ashore.

Obviously there is a wide range in the design and size of dredges of this type. An artificially constructed wet pit in which the deposit consists largely of sand will require a very different dredge from one required in a swiftly running river in which the gravel is coarse. The distance from distribution or storage sites and the rate of production will also affect dredge design. If the dredge is located at a distance from its base it may be necessary to provide living quarters on it for the crew. If production demands are great enough it may be necessary to provide quarters sufficiently large for 2 or even 3 crews to enable continuous operation. Irrespective of whether 1 or 3 shifts are worked the volume of production required will affect the size and therefore the design of the dredge.

The hydraulic dredge thus may perform simply the function of excavation, may combine excavation with transportation, or may combine excavation with either partial or complete treatment. These requirements include the great bulk of hydraulic-dredge installations, and the order in which they are discussed probably represents their relative importance in present use.

There have been further elaborations in design, however, and while these installations are comparatively small in number they account for a considerable tonnage and meet successfully the peculiar requirements of their localities.

In this type of design the pump is installed on a self-propelled lake- or ocean-going vessel. This dredge proceeds under its own power to the excavation site, pumps its hold full of gravel, and returns to the shore plant, thus combining excavation and transportation duties. This design, like that on the larger river or wet-pit dredge, has also been carried further. Machinery has been installed for partial or complete preparation of the dredged product on board. Thus the modern type of dredge may combine all three functions of excavation, transportation, and treatment.

It is obvious that hydraulic-dredge design, construction, and operating characteristics cannot be standardized in any but the simplest fundamentals. Consequently hydraulic dredges cannot be constructed, assembled, and shipped as a factory unit as can shovels, draglines, cranes, and scrapers. The dredge hull may be built at the factory, but except in extremely small sizes it must be assembled and equipped at the site at which it is to be used or at a site from which it can be floated to the excavation point.

As an excavating unit the hydraulic dredge consists of a centrifugal pump with its driving mechanism mounted on a floating vessel of more or less elaborate design.

It requires a natural or artificial body of water from which to operate. It removes gravel from below the surface of the water and can excavate dry banks only by undermining and caving them into the water.

The pump itself does not dig gravel. The force which actually brings the gravel to the pump is the transporting power of water put in motion by the pressure of the atmosphere on the water surface. The function of the pump is to destroy the equilibrium of atmospheric pressure by creating a partial vacuum inside its suction pipe. Once the end of the suction is submerged and the pressure equilibrium destroyed, atmospheric pressure on the surface forces water up the pipe to the pump. The power of the moving water to carry gravel with it depends upon its velocity which depends upon the design and efficiency of the pump.

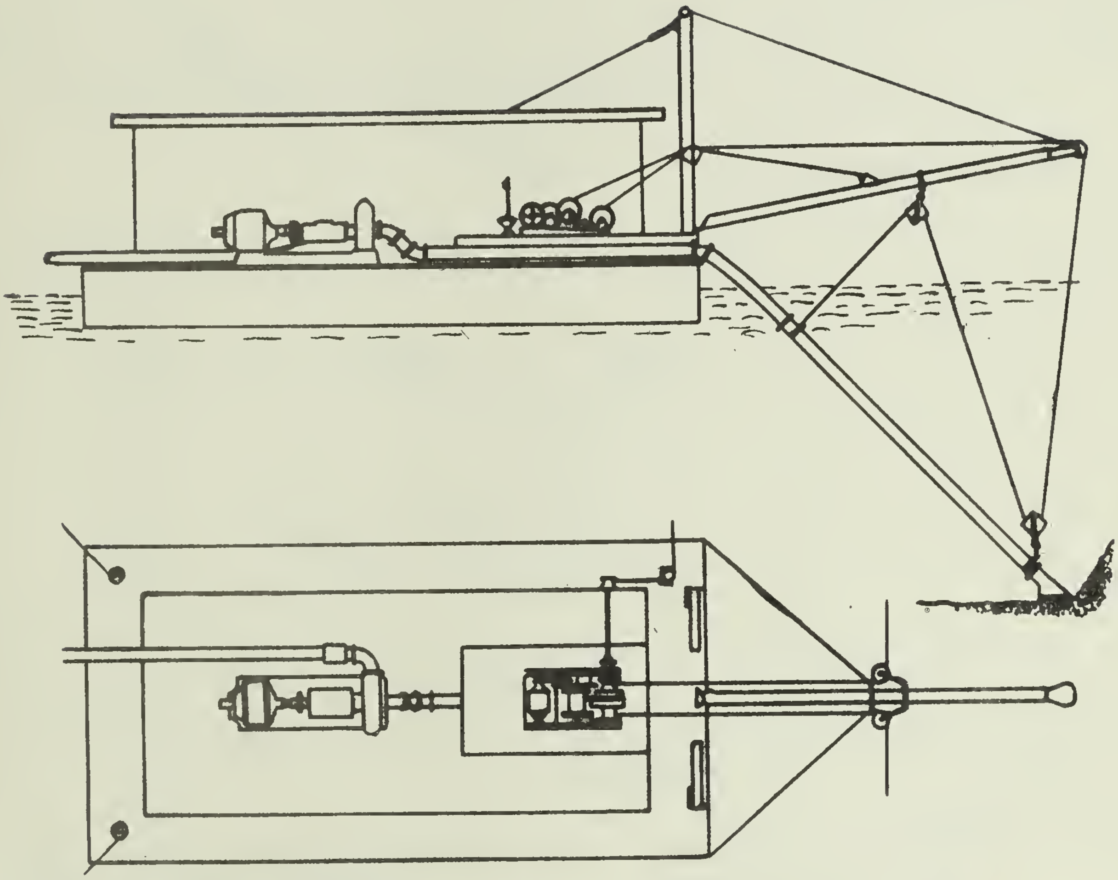

Figure 7.—Plan and elevation of plain hydraulic dredge.

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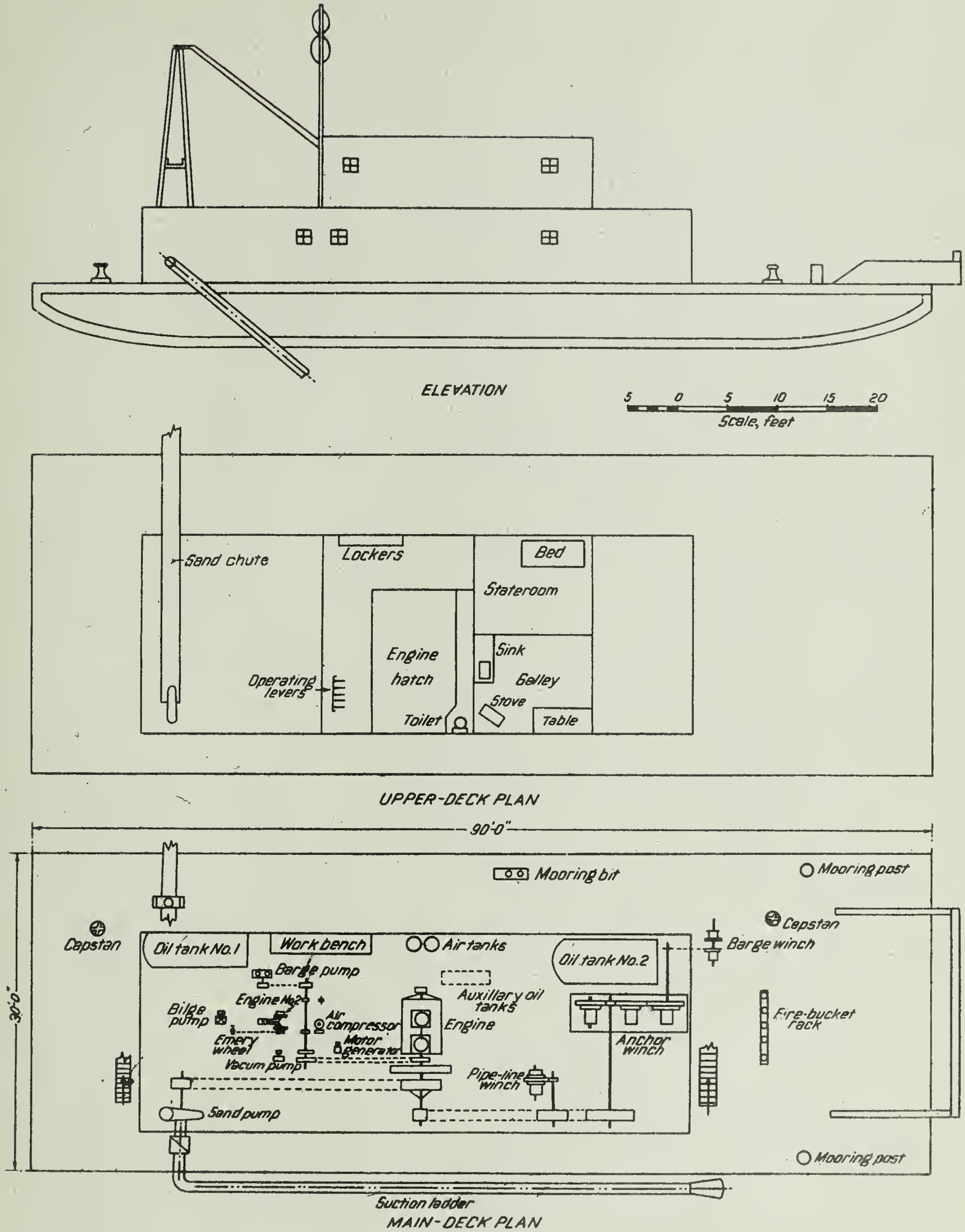


Figure 8.—Side elevation and deck plans of hydraulic dredge with quarters for crew.

If the suction pipe is lowered to the gravel bed while the pump is in operation the inrushing water will carry gravel with it provided that velocity is of sufficient intensity. Thus the hydraulic dredge excavates gravel by creating a vacuum within the suction pipe and thereby permitting natural forces to move the gravel to the pump.

In heavy or cemented gravel a mechanical stirring device is used ahead of the end of the suction pipe to break up the sand and gravel from its natural position so that the water can carry it into the pipe. These devices, however, do not do any actual excavating. They merely disintegrate the material so the water may convey it.

The hydraulic-dredge pump, however, has an added function. When the mixture of water and gravel has once reached the pump it is no longer affected by the atmospheric pressure on the original water surface. From here to the end of the discharge pipe the pump functions as a conveyor. By imparting velocity to the water it causes the water to transport the sand and gravel. The velocity attained depends upon the speed of revolution and the diameter of the pump impeller.

The dredge pump then has two distinct functions, one to create a partial vacuum by which to raise the gravel from the deposit to the pump and one to transport the gravel so raised to the end of the discharge pipe.

In performing both of these functions the pump must do more than actually lift and move the mixture of gravel and water. Water moving within a confined area such as the suction or discharge pipes creates friction with the inner walls of the pipe. Sand and gravel mixed with the water so moving greatly increase that friction. The pump must not only move the mixture, but it must move it against the friction which that very motion creates.

If the end of the discharge pipe is level with the pump, the pressure or head required to transport gravel is only that necessary to overcome friction in the pipe. If the end is below the pump the discharge pressure will be assisted by the action of gravity. If the end of the pipe is above the pump the pressure must be sufficient to overcome the action of gravity in raising the mixture of water and gravel that distance in addition to overcoming friction.

Thus it is evident that the hydraulic dredge pump must perform a number of functions which are assisted or retarded by natural phenomena. It must create conditions that permit natural forces to lift water and gravel from the deposit to the pump. In this it is assisted by the atmospheric pressure on the water surface. It is retarded first by the friction created by the material entering the suction, second by the friction created by the material traveling through the pipe, and third by the force of gravity.

It must force water and gravel through the discharge pipe. In this it is retarded by the friction created within the pipe and may be retarded or assisted by gravity according to whether the discharge outlet is above or below the pump. The latter seldom occurs in commercial practice.

Since the operation of an hydraulic dredge involves the movement of a liquid comprising 80 to 95 percent of water and 5 to 20 percent by volume of sand and gravel, obviously an understanding of the principles under which it operates must comprehend at least a fundamental knowledge of the laws of hydraulics and such modification of them as may be required by the handling of mixtures of sand, gravel, and water.

One of the important natural phenomena involved is the pressure of the atmosphere on the water surface. At sea level this is 14.7 pounds per square inch, and it extends equally in all directions.

For all practical purposes water is incompressible. Technically this is not true, but its compressibility depends upon its temperature and the amount of air in solution. The average change in volume is about 1 percent for a pressure of 3,000 pounds per square inch. Such a change due to pressure is too small to cause serious error in hydraulic calculations; hence it is disregarded.

Now since water is incompressible and the pressure of the atmosphere is equal on every square inch of the exposed surface, that pressure is automatically communicated to all material lying below the surface of the water without reduction. Therefore the particles of a submerged gravel deposit are at all times under a pressure equal to the weight of the atmosphere plus the weight of the water above them.

Atmospheric pressure decreases roughly 1/2 pound per square inch for each 1,000 feet of elevation above sea level; therefore the pressure available to assist the pump varies with the elevation of the water surface above sea level.

Atmospheric pressure is commonly measured by the mercurial barometer. If a glass tube of any convenient diameter and any length is closed at one end, filled with mercury to the exclusion of all air, and then inverted with the open end immersed in an open bowl of mercury a certain amount of the mercury in the tube will run out into the dish. Since the upper end of the tube is closed, a vacuum will be formed equal in volume to the mercury that has run out. This constitutes a mercurial barometer in its simplest form. The atmospheric pressure is measured in inches of mercury column between the surface of the mercury in the dish and the top of the column in the tube.

At sea level the column of mercury will stand 30 inches high. Therefore 14.7 pounds per square inch of atmospheric pressure will sustain a 30-inch column of mercury, or, as commonly expressed, 14.7 pounds atmospheric pressure equals 30 inches vacuum. For each 1,000 feet of elevation above sea level the mercury column drops approximately 1 inch. Therefore, since a 1,000-foot change in elevation equals a change of 1 inch in vacuum and 1/2 pound per square inch in atmospheric pressure, obviously if either be known at any particular point the other may be calculated from it.

Now if instead of mercury in the tube water is used and the open end is inverted and immersed in a tank of water, the column in the tube at sea level will stand 34 feet high. Therefore a 30-inch vacuum represents a 34-foot water column and each represents 14.7 pounds atmospheric pressure.

This means that if a pump were capable of producing a perfect vacuum at sea level it could draw water from a source the surface of which was 34 feet below the pump. In other words, the same pump at 30-inch vacuum could raise water against a 34-foot suction head.

Since a 30-inch vacuum corresponds to a 34-foot suction head, each inch of change in vacuum will correspond to 1.13 feet of change in suction head. Thus a pump required to draw water against a 28-foot suction head must be capable of producing 28 divided by 1.13 or 24.8 inches of vacuum. This is approximately the maximum lift obtainable in commercial practice.

The revolution of the pump impeller creates a partial vacuum within the pump casing and the suction pipe. The degree of vacuum created will depend upon the shape of the impeller vanes, the clearance space between impeller and pump casing, the speed of rotation, and the diameter of the impeller. These, of course, may vary greatly due to differences in design and construction of impellers and pumps.

A dredging pump is nothing more than a side-suction centrifugal pump, differing in construction from a water pump of that description only in that it has larger clearances through the impeller and casing to enable it to pass large-size solids and that the parts are extra-heavy and of wear-resisting materials to resist wear and abrasion occasioned by the material passing through.

In operation its function is to pump a stream of water into which is introduced a certain percentage of solids. The principal points of difference in operation between a dredging pump and a centrifugal side-suction water pump of similar size and characteristics are that the dredging pump has a somewhat lower mechanical efficiency, a lower drop in head for a given increase in capacity, and a tendency to overload the driver with an increase in capacity or drop in head. All of these differences are occasioned by the fact that a dredging pump must have larger clearances and ports to be able to handle large-size solids.

The first duty of the pump is to create a partial vacuum within its casing and suction pipe. The vacuum thus produced is used for several purposes, as follows: (1) To produce velocity in the water ascending the suction pipe; (2) to overcome friction in the suction pipe caused by the moving mixture; (3) to raise the sand, gravel, and water to the surface of the water; (4) to lift the mixture from the surface of the water to the center line of the pump; and (5) to overcome the inertia of the sand and gravel and cause it to move into the suction pipe.

One inch of vacuum corresponds to 1/2 pound per square inch of atmospheric pressure; therefore a pump capable of producing 20 inches of vacuum would create 10 pounds per square inch difference in atmospheric pressure between the interior of its suction and the surface of the water outside. Since the vacuum produced is independent of the diameter of the suction and discharge pipes, evidently the total static-pressure differential created by different sizes of pumps will vary as the square of the diameter, although the vacuum will remain the same. In other words, while the difference in static pressure per square inch remains constant for a constant vacuum, the total static pressure differential varies with the cross-sectional area of the suction pipe.

One inch of vacuum is equivalent to 1.13 feet of static head or water barometer. Therefore a pump capable of producing 25 inches of vacuum will make available 28.33 feet of static head to perform the five tasks enumerated above.

Table 30 presents the equivalent of static head for each inch of vacuum.

TABLE 30.- Static head in terms of vacuum

Vacuum, inches	Static head, feet	Vacuum, inches	Static head, feet
1	1.133	16	18.13
2	2.267	17	19.27
3	3.400	18	20.40
4	4.530	19	21.52
5	5.670	20	22.67
6	6.800	21	23.80
7	7.940	22	24.93
8	9.070	23	26.07
9	10.17	24	27.20
10	11.333	25	28.33
11	12.470	26	29.47
12	13.60	27	30.60
13	14.73	28	31.73
14	15.87	29	32.87
15	17.00	30	34.00

The degree of vacuum produced by a centrifugal pump is ascertained by reading the gage placed on the upper end of the suction pipe near the pump. A comparison of the observed reading with table 30 will show the static head available to perform the functions required of the pump.

Calculation of the force required to impart velocity to the water in the suction pipe follows the laws of falling bodies and may be reduced to a formula, as follows:

Let $\underline{V}$ represent the final velocity in feet per second, g the acceleration or 32.16, and $\underline{h}$ the static head in feet required to produce the desired velocity. Then

$$\underline{V}^2 = 2\ \underline{gh} \text{ and } \underline{h} = \underline{V}^2/2\underline{g}.$$

From this formula the velocity head may be derived (disregarding friction) for any desired velocity. Experience has shown that sand and gravel pumps operate most efficiently at velocities ranging from 5 to 18 feet per second.

Table 31 gives the static head required to produce velocities within this range. The minimum velocity is probably too low for usual practice and would be permissible only under specific conditions. Modern practice tends toward increased velocity.

TABLE 31.- Static head required to produce various velocities

Velocity, feet per second	Static head required, feet	Velocity, feet per second	Static head required, feet
5	0.39	12	2.24
6	.56	13	2.63
7	.76	14	3.05
8	.995	15	3.50
9	1.26	16	3.98
10	1.55	17	4.50
11	1.88	18	5.04

The velocity required at any designated installation will depend upon several factors, including the size of gravel particles, length and elevation of discharge line, etc. Customarily the speed of the pump is set for velocities of 10 to 12 feet per second for sand and gravel excavation.

The head required to overcome friction in the suction pipe depends upon a number of factors, such as (1) the internal diameter of the pipe, (2) the condition of the internal surface of the pipe, and (3) the velocity of flow.

Various formulas for the determination of friction head have been prepared by different authorities on hydraulics. All are empirical in that they involve the use of constants determined by experiment to represent the effect of the condition of the interior surface of the pipe. For instance, the effect of seams and rivet heads in the interior of spiral pipe will be to increase frictional resistance above that required for new, smooth, cast-iron or steel pipe. Bends and curves will also increase frictional resistance, but since suction pipes are usually short and straight or have curves of large diameter the loss from this cause is usually disregarded.

As ordinarily published, tables of friction head are for clean water flowing in straight smooth pipes. A mixture of sand and gravel in the water will increase the frictional resistance, depending upon the size of the particles. Since the average size of particles will vary not only for every deposit but for each particular portion of any deposit, it is impossible to reduce this effect accurately to a formula that will apply to all conditions except by citing minimum and maximum limits which have been determined by experience.

Table 32 presents minimum and maximum friction heads for sand, gravel, and water mixtures at various velocities in various sizes of pipes. In sand and gravel dredging the losses due to friction appear to follow Williams and Hazens' tables for clear water based on their exponential formula using C = 100. In obtaining the figures for the frictional head for sand, gravel, and water mixtures Williams and Hazens' table has been increased 10 percent to obtain the minimum figure and 50 percent to obtain the maximum. The 10 percent increase is calculated to represent not over 10 percent sand with little gravel. More sand or a larger ratio of gravel requires a further increase up to the maximum of 50 percent. These are arbitrary estimates offered by the author. Accurate measurement of friction in sand and gravel dredging is difficult if not impossible for obvious reasons.

Since the maximum static head available with a pump creating a perfect vacuum is 34 feet, obviously the higher velocities in the smaller-diameter pipes would produce such high friction heads as to prevent their pumping sand and gravel at all, even neglecting other head losses.

TABLE 32.- Friction head for sand, gravel, and water mixtures in feet per 100 feet of straight, smooth pipe

(Calculated from Williams and Hazens' hydraulic tables; C = 100)

Velocity, feet per second	Pipe diameters, inches									
	4		5		6		8		10	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
5	4.6	6.3	3.6	4.9	2.9	3.9	2.0	2.8	1.6	2.2
6	6.0	8.1	5.0	6.8	4.0	5.5	2.9	4.0	2.2	3.1
7	8.7	12.0	6.7	9.1	5.4	7.3	3.9	5.3	3.0	4.0
8	11.0	15.1	8.6	11.7	6.9	9.4	5.0	6.8	3.8	5.2
9	13.9	18.9	10.6	14.5	8.5	11.6	6.2	8.4	4.7	6.5
10	16.7	22.8	12.9	17.6	10.4	14.1	7.5	10.2	5.7	7.8
11	20.0	27.3	15.4	21.0	12.7	17.3	8.9	12.1	6.9	9.4
12	23.4	32.0	18.1	24.8	15.0	20.4	10.5	14.2	8.1	11.0
13	27.3	...	21.0	28.7	17.3	23.6	12.2	16.2	9.4	12.8
14	31.2	...	24.2	33.0	19.8	27.0	14.1	19.2	10.8	14.7
15	...	...	27.4	...	22.5	30.6	16.0	21.8	12.2	16.6
16	...	...	30.8	...	25.3	34.5	18.0	24.6	13.7	18.7
17	...	...	34.4	...	28.4	...	20.2	27.4	15.4	21.0
18	...	...	...	...	31.4	...	22.3	30.4	17.2	23.4

Velocity, feet per second	Pipe diameters, inches									
	12		14		16		18		20	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
5	1.3	1.7	1.1	1.5	0.9	1.3	0.8	1.1	0.7	1.0
6	1.8	2.5	1.5	2.1	1.3	1.8	1.1	1.5	1.0	1.3
7	2.4	3.3	2.0	2.8	1.7	2.4	1.5	2.0	1.3	1.8
8	3.1	4.2	2.6	3.5	2.2	3.0	1.9	2.6	1.7	2.3
9	3.8	5.2	3.2	4.4	2.8	3.7	2.4	3.3	2.1	2.9
10	4.6	6.3	3.9	5.3	3.3	4.6	2.9	4.0	2.6	3.5
11	5.5	7.5	4.7	6.5	4.0	5.4	3.5	4.7	3.1	4.2
12	6.5	8.8	5.5	7.6	4.7	6.6	4.1	5.5	3.6	4.9
13	7.5	10.2	6.5	8.8	5.4	7.4	4.7	6.5	4.2	5.7
14	8.6	11.7	7.4	10.2	6.3	8.5	5.4	7.4	4.8	6.6
15	9.8	13.3	8.4	11.5	7.1	9.7	6.2	8.3	5.5	7.5
16	11.0	15.0	9.5	12.9	8.0	11.0	6.9	9.5	6.2	8.4
17	12.5	17.0	10.6	14.5	9.0	12.3	7.8	10.6	6.9	9.5
18	13.7	18.7	11.8	16.0	10.0	13.6	8.6	11.8	7.7	10.5

Since internal pipe friction is a function of the diameter of the pipe and the velocity of flow, any increase in diameter will decrease friction but will also reduce velocity. In

some installations it is feasible to increase the size of the suction pipe and thereby reduce the velocity of the material entering the pump. This is not possible in all cases or to an unlimited degree because such a reduction in velocity may destroy the transporting power of the entering water.

Table 33 shows the capacity in cubic feet of various sizes of pipe for material traveling at different velocities.

The pump vacuum must next be utilized to lift the sand and gravel from the deposit to the surface of the water. For purposes of illustration the suction pipe may be considered as one leg of a U tube, the other leg being the body of water in which the suction is submerged. If the U tube is set upright with its open ends upward and water poured in one side, the water will come to rest at the same height in both legs irrespective of their length, inclination, or relative diameter. Similarly, while the pump is idle and the suction pipe submerged, the water inside is at the same elevation as that outside the pipe.

TABLE 33.- Capacity of pipe in cubic feet per minute at various velocities

Velocity, feet per second	Pipe diameter, inches									
	4	5	6	8	10	12	14	16	18	20
5	26	41	59	104	164	236	321	418	530	655
6	31	49	71	125	196	283	385	502	636	786
7	37	57	83	146	229	330	449	586	743	918
8	42	66	94	167	262	377	513	670	849	1,049
9	47	74	106	188	295	423	577	754	955	1,180
10	52	82	118	209	327	471	642	838	1,061	1,311
11	58	90	130	230	360	518	706	922	1,167	1,443
12	63	98	141	251	392	565	770	1,006	1,273	1,574
13	68	106	153	272	425	612	834	1,090	1,379	1,705
14	73	115	165	292	458	659	898	1,173	1,486	1,836
15	79	123	177	313	491	706	962	1,256	1,592	1,967
16	84	131	189	334	523	754	1,026	1,340	1,698	2,098
17	89	139	200	355	556	801	1,090	1,424	1,804	2,229
18	94	147	212	376	589	848	1,154	1,508	1,910	2,360

Now, if an impervious but frictionless partition is placed in the U tube at the center of the bend and water is placed in one leg to a height of 34 feet and mercury in the other to a height of 30 inches the two columns will retain these same heights even though the separating partition is free to move without friction. Mercury is 13.6 times as heavy as an equal volume of water or has a specific gravity of 13.6. It will be noted that the height of the water column (34 feet) is 13.6 times the height of the mercury column (30 inches). Therefore, when water is placed in one leg of the U tube, an equal weight of a liquid of different specific gravity in the other, and some means introduced to prevent their intermixing, the heights of the columns will vary inversely as their specific gravities.

Assuming the partition between the water and mercury has no weight and offers no frictional resistance to movement but still prevents either water or mercury to pass, then pressure may be applied to the water leg or pressure removed at the mercury leg and the two columns brought to the same level in each tube. The application of vacuum to the mercury tube illustrates the function of the pump in bringing sand and gravel to the surface of the water.

If instead of mercury one leg of the tube is filled with mixtures of sand, gravel, and water in which the quantity of sand and gravel ranges from 5 to 15 percent as ordinarily found in practice, one can calculate the feet of head required to bring the two columns to the same height. It is assumed of course that the sand and gravel remain dispersed and suspended in the water to form a homogeneous liquid.

Water weighs 62.5 pounds per cubic foot. Sand and gravel varies in weight but may be assumed to average 110 pounds per cubic foot. A cubic foot of sand and gravel, however, contains a certain amount of voids between the particles. An average void content may be assumed to be 40 percent. Five cubic feet of dry sand contains 40 percent voids or 2 cubic feet of air space. If this is mixed with 97 cubic feet of water the resulting volume will be 100 cubic feet, of which 5 cubic feet or 5 percent will be solids. Fifteen cubic feet of dry sand contains 40 percent or 6 cubic feet of voids. If this is mixed with 91 cubic feet of water the resulting volume will again be 100 cubic feet, of which 15 cubic feet or 15 percent will be solids. The weights of these two mixtures will be as follows:

Weight of mixtures

	5 percent solids		15percent solids	
	Pounds	Cu. ft.	Pounds	Cu. ft.
Water	5,937.5	95	5,312.5	85
Water in voids	125	2	375	6
Sand and gravel	550	5	1,650	15
	6,612.5		7,337.5	

The weight of the mixture will range from 66 to 73 pounds per cubic foot or will have a specific gravity of 1.06 to 1.17. If equal weights of the mixture are placed in one leg of the U tube and clear water is placed in the other, the clear water column will be 1.06 to 1.17 times the height of the mixture column. This means that the water in the pond or lake will maintain a column of mixture of sand, gravel, and water in the suction pipe ranging from 94 to 85 percent of the vertical depth of submergence of the suction pipe. The head required to bring the mixture to the same level as the outside water is then 6 to 15 percent of the submergence, measured vertically, multiplied by the specific gravity of the mixture. Completing the multiplication, the head necessary to bring the mixture to the surface of the water will range from 6.4 percent of the vertical submergence for 5-percent solids to 17.5 percent for a 15-percent mixture.

Table 34 presents the head in feet required to bring the mixture to the surface for different percentages of solids and different vertical depths of submergence.

The pump, having raised the mixture of sand, gravel, and water to the surface of the pond, must continue and raise it to the center line of the pump. The distance from the center line of the pump to the water surface is the suction lift. As has been shown a perfect vacuum will raise clear water against a 34-foot suction head if friction is omitted from the calculation. The material handled by the pump, however, is not clear water but is heavier. As seen in table 34, the specific gravity will range from 1.01 for a mixture containing 1 percent to 1.46 for a mixture containing 40 percent solids. The head required to raise this mixture from the water surface is the suction lift in feet multiplied by the specific gravity of the mixture.

TABLE 34.- Feet of head required to bring sand, gravel, and water to the water surface

Solids, percent	Specific gravity	Vertical submergence, feet													
		2	4	6	8	10	12	14	16	18	20	22	24	26	28
1	1.01	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28
2	1.02	.04	.08	.12	.16	.20	.24	.29	.33	.37	.41	.45	.49	.53	.57
3	1.04	.08	.17	.25	.33	.42	.50	.58	.67	.75	.83	.92	1.00	1.08	1.17
4	1.05	.10	.20	.30	.40	.50	.60	.70	.80	.90	1.01	1.11	1.21	1.31	1.41
5	1.06	.12	.24	.36	.48	.60	.72	.84	.96	1.08	1.20	1.32	1.44	1.56	1.68
6	1.07	.14	.28	.42	.56	.70	.83	.97	1.11	1.25	1.39	1.53	1.67	1.81	1.95
7	1.08	.16	.32	.48	.64	.80	.96	1.12	1.28	1.44	1.60	1.76	1.92	2.08	2.24
8	1.09	.18	.36	.54	.72	.90	1.09	1.27	1.45	1.63	1.81	1.99	2.17	2.35	2.53
9	1.10	.20	.40	.59	.79	.99	1.19	1.39	1.58	1.78	1.98	2.18	2.38	2.57	2.77
10	1.12	.24	.48	.72	.96	1.20	1.44	1.68	1.92	2.16	2.40	2.64	2.88	3.12	3.36
11	1.13	.26	.52	.78	1.04	1.30	1.56	1.82	2.08	2.34	2.60	2.86	3.12	3.38	3.64
12	1.14	.28	.56	.84	1.12	1.40	1.68	1.96	2.24	2.53	2.80	3.09	3.37	3.65	3.93
13	1.15	.30	.60	.90	1.20	1.50	1.80	2.09	2.39	2.69	2.99	3.29	3.59	3.89	4.19
14	1.16	.32	.64	.96	1.28	1.60	1.92	2.24	2.56	2.88	3.20	3.52	3.84	4.16	4.48
15	1.17	.34	.68	1.02	1.36	1.70	2.04	2.38	2.72	3.05	3.40	3.73	4.07	4.41	4.75
20	1.23	.46	.92	1.38	1.84	2.30	2.76	3.22	3.68	4.14	4.60	5.06	5.52	5.98	6.44
25	1.29	.58	1.16	1.74	2.32	2.90	3.48	4.06	4.64	5.22	5.80	6.38	6.96	7.54	8.12
30	1.32	.64	1.28	1.92	2.56	3.20	3.84	4.48	5.12	5.76	6.40	7.04	7.68	8.32	8.86
40	1.46	.93	1.86	2.79	3.72	4.65	5.58	6.50	7.44	8.37	9.30	10.20	11.20	12.10	13.00

Solids, percent	Specific gravity	Vertical submergence, feet											
		30	32	34	36	38	40	50	60	70	80	90	100
1	1.01	0.30	0.32	0.34	0.36	0.38	0.40	0.50	0.60	0.70	0.80	0.90	1.01
2	1.02	.61	.65	.69	.73	.77	.82	1.02	1.22	1.43	1.63	1.84	2.04
3	1.04	1.25	1.33	1.42	1.50	1.58	1.62	2.08	2.50	2.91	3.33	3.75	4.16
4	1.05	1.51	1.61	1.71	1.81	1.91	2.02	2.52	3.02	3.53	4.04	4.54	5.04
5	1.06	1.80	1.92	2.04	2.16	2.28	2.40	3.00	3.60	4.20	4.80	5.40	6.00
6	1.07	2.09	2.23	2.37	2.50	2.64	2.78	3.48	4.17	4.87	5.56	6.26	6.96
7	1.08	2.40	2.56	2.72	2.88	3.07	3.20	4.00	4.80	5.60	6.40	7.20	8.00
8	1.09	2.72	2.90	3.08	3.26	3.44	3.62	4.52	5.43	6.34	7.24	8.14	9.05
9	1.10	2.97	3.17	3.37	3.56	3.76	3.96	4.95	5.94	6.93	7.92	8.91	9.90
10	1.12	3.60	3.84	4.08	4.32	4.56	4.80	6.00	7.20	8.40	9.60	10.80	12.00
11	1.13	3.90	4.16	4.42	4.68	4.94	5.20	6.50	7.80	9.10	10.40	11.70	13.00
12	1.14	4.20	4.49	4.77	5.05	5.33	5.61	7.02	8.42	9.82	11.20	12.60	14.00
13	1.15	4.49	4.79	5.08	5.38	5.68	5.98	7.48	8.97	10.50	12.00	13.50	15.00
14	1.16	4.80	5.12	5.44	5.60	6.08	6.40	8.00	9.60	11.20	12.80	14.40	16.00
15	1.17	5.09	5.43	5.77	6.11	6.45	6.79	8.50	10.20	11.90	13.60	15.30	17.00
20	1.23	6.90	7.36	7.82	8.28	8.74	9.20	11.50	13.80	16.10	18.40	20.70	23.00
25	1.29	8.70	9.28	9.86	10.40	11.00	11.60	14.50	17.40	20.60	23.20	26.20	29.00
30	1.32	9.60	10.20	10.90	11.50	12.20	12.80	16.00	19.20	22.40	25.60	28.80	32.00
40	1.46	14.00	14.90	15.80	16.70	17.70	18.60	23.20	27.80	32.50	37.20	41.80	46.50

Table 35 presents the head required to raise mixtures of different percentages of solids through different distances of suction lift.

The head required to dislodge the sand and gravel from place and start it moving through the suction pipe is an indefinite quantity varying from moment to moment depending upon the size and shape of the particles and their degree of cementation in the deposit. The head available for this purpose is found by difference after subtracting the sum of all other requirements from the head available at the pump due to the vacuum produced.

To illustrate the use of the tables and the effect of varying conditions at a single installation, assume that an 8-inch pump is producing 25 inches of vacuum and is pumping a mixture of 10 percent solids at a velocity of 10 feet per second and discharging free into the air at the pump. Examples cited will use variations in suction head of 2 and 5 feet, of lengths of suction pipe of 50 and 100 feet, of diameter of suction of 8 and 10 inches, and of submergence of the gravel below the water surface of 15 and 40 feet. Only 8 combinations of these 4 variables are shown. It must be borne in mind also that the four conditions assumed in this example are also variable. Hence only a few of the possible combinations are worked out mathematically in table 36.

TABLE 35.- Feet of head required to raise sand, gravel, and water mixtures against suction lift

Solids, percent	Specific gravity	Suction lift, feet												
		1	2	3	4	5	6	7	8	9	10	12	14	16
1	1.01	1.01	2.02	3.03	4.04	5.05	6.06	7.07	8.08	9.09	10.10	12.12	14.14	16.16
2	1.02	1.02	2.04	3.06	4.08	5.10	6.12	7.14	8.16	9.18	10.20	12.24	14.28	16.32
3	1.04	1.04	2.08	3.12	4.16	5.20	6.24	7.28	8.32	9.36	10.40	12.48	14.56	16.64
4	1.05	1.05	2.10	3.15	4.20	5.25	6.30	7.35	8.40	9.45	10.50	12.60	14.70	16.80
5	1.06	1.06	2.12	3.18	4.24	5.30	6.36	7.42	8.48	9.54	10.60	12.72	14.84	16.96
6	1.07	1.07	2.14	3.21	4.28	5.35	6.42	7.49	8.56	9.63	10.70	12.84	14.98	17.12
7	1.08	1.08	2.16	3.24	4.32	5.40	6.48	7.56	8.64	9.72	10.80	12.96	15.12	17.28
8	1.09	1.09	2.18	3.27	4.36	5.45	6.54	7.63	8.72	9.81	10.90	13.08	15.26	17.44
9	1.10	1.10	2.20	3.30	4.40	5.50	6.60	7.70	8.80	9.90	11.00	13.20	15.40	17.60
10	1.12	1.12	2.24	3.36	4.48	5.60	6.72	7.84	8.96	10.08	11.20	13.44	15.68	17.92
11	1.13	1.13	2.26	3.39	4.52	5.65	6.78	7.91	9.04	10.17	11.30	13.56	15.82	18.08
12	1.14	1.14	2.28	3.42	4.56	5.70	6.84	7.98	9.12	10.26	11.40	13.68	15.96	18.24
13	1.15	1.15	2.30	3.45	4.60	5.75	6.90	8.05	9.20	10.35	11.50	13.80	16.10	18.40
14	1.16	1.16	2.32	3.48	4.64	5.80	6.96	8.12	9.28	10.44	11.60	13.92	16.24	18.56
15	1.17	1.17	2.34	3.51	4.68	5.85	7.02	8.19	9.36	10.53	11.70	14.04	16.38	18.72
20	1.23	1.23	2.46	3.69	4.92	6.15	7.38	8.61	9.84	11.07	12.30	14.76	17.22	19.18
25	1.29	1.29	2.58	3.87	5.16	6.45	7.74	9.03	10.32	11.61	12.90	15.48	18.06	20.64
30	1.32	1.32	2.64	3.96	5.28	6.60	7.92	9.24	10.56	11.88	13.20	15.84	18.48	21.12
40	1.46	1.46	2.92	4.38	5.84	7.30	8.76	10.22	11.68	13.14	14.60	17.52	20.44	23.36

TABLE 36.- Head required by various combinations of conditions

	A		B		C		D	
Suction lift.....feet	2		2		2		2	
Suction length.....do.	50		50		50		100	
Suction diameter.....inches	8		8		10		10	
Vertical submergence.....feet	15		40		40		40	
Static head required for velocity (10 ft. per sec. in 8 in. pipe equivalent volume in 10 in.) (tables 31-33).....	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
	1.55	1.55	1.55	1.55	0.64	0.64	0.64	0.64
Friction (tables 32-33).....	3.75	5.10	3.75	5.10	1.25	1.75	2.26	3.46
Raising material to surface (table 34).....	1.80	1.80	4.80	4.80	4.80	4.80	4.80	4.80
Raising material to the pump (table 35).....	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
Total head required.....	9.34	10.69	12.34	13.69	8.93	9.43	9.94	11.14
Since the head available at the pump was 28.33 feet (25 inches vacuum), the head available to move gravel is.....	18.99	17.64	15.99	14.64	19.40	18.90	18.39	17.19

	E		F		G		H	
Suction lift.....feet	5		5		5		5	
Suction length.....do.	50		50		50		100	
Suction diameter.....inches	8		8		10		10	
Vertical submergence.....feet	15		40		40		40	
Static head required for velocity (10 ft. per sec. in 8 in. pipe equivalent volume in 10 in.) (tables 31-33).....	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
	1.55	1.55	1.55	1.55	0.64	0.64	0.64	0.64
Friction (tables 32-33).....	3.75	5.10	3.75	5.10	1.25	1.75	2.26	3.46
Raising material to surface (table 34).....	1.80	1.80	4.80	4.80	4.80	4.80	4.80	4.80
Raising material to the pump (table 35).....	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60
Total head required.....	12.70	14.05	15.70	17.05	12.29	12.79	13.30	14.50
Since the head available at the pump was 28.33 feet (25 inches vacuum), the head available to move gravel is.....	15.63	14.28	12.63	11.28	16.04	15.54	15.03	13.83

By following the examples cited and substituting values for any local combination of conditions, the reader will be able to ascertain the range of possibilities for his particular installation.

THE PUMP AS A TRANSPORTING AGENT

In the previous discussion the function of the pump has been to excavate gravel and sand and bring them to the pump itself. Sand and gravel pumps as usually installed must do more than this. They must transport the mixture of sand, gravel, and water beyond the pump through a discharge pipe to the barge or treatment plant. This involves calculation of the friction set up within the discharge pipe and the elevation of the point of discharge above the pump.

The friction in the discharge pipe is calculated in the same way as in the suction pipe, hence table 32 may be used to ascertain the total friction head necessary for any length of discharge pipe for minimum and maximum conditions at different velocities of flow.

When a pump discharges through an elevated discharge pipe, it must lift the material pumped through a vertical distance equal to the difference in elevation of the center of the pump and the end of the discharge. The head required to do this is equal to the vertical distance in feet.

POWER REQUIREMENTS

The power required to operate a sand and gravel pump may be computed from the formula

$$P = QWH/33,000$$

in which P equals the theoretical horsepower, Q the quantity of material handled in cubic feet per minute, W the weight of a cubic foot of the material handled, and H the total head against which the pump is working, and 33,000 the foot-pounds per minute corresponding to 1 hp.

The quantity of material handled in cubic feet per minute depends upon the diameter of the discharge pipe and the velocity of flow. This may be read directly from table 33.

The weight of a cubic foot of the material handled is the product of the weight of a cubic foot of water and the specific gravity of the material handled. Specific gravities of mixtures with varying percentages of solids are given in table 35, and a cubic foot of water weighs 62.5 pounds.

The total head against which the pump must operate is the sum of the suction head, the static head, and the friction head.

The suction head is obtained by reading the vacuum gage on the suction pipe close to the pump and converting this into feet by reference to table 30.

The static head with the usual arrangement of discharge pipe is the vertical height of the end of the discharge pipe above the center of the pump.

The friction head may be calculated from table 32 for various lengths of pipe.

As an example, assume the same 8-inch pump producing 25 inches of vacuum is pumping 10 percent solids at 12 feet per second through an 8-inch discharge pipe 200 feet long, the end of which is 20 feet above the pump.

Table 33 shows that the quantity of material delivered from an 8-inch pipe at a velocity of 12 feet per second is 251 cubic feet per minute, or Q in the formula.

From table 35 the specific gravity of a mixture containing 10 percent solids is 1.12 and the weight W of a cubic foot will be 62.5 times 1.12 or 70 pounds.

	Feet
Suction head (from table 30)	28.33
Static head	20.00
Friction head (from table 32 it will range from 10.5 to 14.2 feet per 100 feet of discharge pipe. Assume an average of 12.35 feet)	24.70
Total head	73.03

Solving in the equation then

$$P = 251 \times 70 \times 73.03/33,000 = 39 \text{ hp.}$$

Sand and gravel pumps by actual test have shown efficiencies as high as 78 percent. Experience, however, shows that when computing the rating of the necessary motive power to apply to a given set up, it is best to assume 50 percent efficiency and select the drive accordingly. Therefore, the theoretical or water horsepower in this case would be 39, and the brake horsepower or motor rating would be 78 or 80.

Operating Limitations

For the same reasons that it is impossible to tabulate pump capacities it is also impossible to tabulate operating limitations.

As has been shown in the discussion of the characteristics of dredging pumps the depth from which gravel may be pumped depends largely upon the friction in the suction pipe. This involves computation based principally on the length and diameter of the suction pipe, either of which may be altered at will.

The ability of a pump to overcome suction head is directly proportional to the amount of vacuum of which it is capable, and this in turn depends upon the amount of clearance between the impeller vanes and the pump casing, which is a matter of individual pump design. The only positive statement regarding all pumps that can be made in this connection is as follows: In order to pump gravel the vacuum produced by a pump must be sufficient to overcome the total suction head and is limited to the portion of the natural head produced by atmospheric pressure that the pump is capable of utilizing, that is, the vacuum it is able to develop.

The space between impellers and casing is designed for each particular pump size and may vary with the design of various manufacturers. Except within a very small range it is not subject to change by increasing impeller diameter in any individual pump. The clearance will generally permit the passage of material ranging in diameter from 60 to 75 percent of the diameter of the pump intake. By this is meant the suction opening of the pump itself and not the suction pipe. The approximate maximum limits of material permissible for various sizes of pumps follow:

Size of pump, inches	Maximum size of particle, inches
4	2.375
6	4.125
8	5.875
10	7.500
12	9.25
15	11.00
20	14.00

It is obvious that the size of the average particle or the size of the maximum particles in a deposit will affect the size of the pump to be used. For instance, a deposit containing an appreciable percentage of boulders averaging 6 inches in diameter would not warrant the installation of a pump with less than a 10-inch suction opening and might even require a 12-inch opening. Any deposit containing boulders averaging 6 inches in diameter will have a considerable quantity of larger size, hence a 10-inch pump with 7.5-inch clearance would suffer from frequent blocking in the suction line. This might occur even in a 12-inch pump. If boulders of this size form an important portion of the deposit it would be preferable to increase the pump size to 20 inches. The reason for this is that the diameter of the suction opening to minimize stoppage should be at least three times the diameter of the average large

particles. If the ratio of boulders to fine particles is too great some other type of dredge is preferable. It is difficult to set an arbitrary limit on this ratio, but ordinarily a pump would be entirely unsuitable for excavating a deposit in which 10 percent of the gravel is larger than the clearance limit of the pump. This rule applies even though the dredge is equipped with a traveling or rotary screen. Without such auxiliary equipment the clearance limit of the pump should exceed the diameter of the largest particles, except of course that of the occasional large boulders common to most deposits.

Hydraulic pumps without supplementary equipment such as traveling or rotary screens cannot be used to excavate cemented gravel. As shown in the previous discussion of pump functions the force which moves the sand and gravel into the pump suction is the static head available after friction and other suction losses have been provided for. Even at a maximum this is incapable of destroying the bond between particles of cemented material or even consolidated hardpan. By the use of traveling or rotary screens hardpan or cemented gravel of considerable firmness can be broken up by the moving blades of the screen, and when so disintegrated the pump can excavate it. The degree of cementation or consolidation which can be broken up with such auxiliary equipment depends upon the mechanical construction and strength of the screens, a discussion of which is not within the scope of this paper.

A dredge pump should at all times be placed as near the surface of the water as possible. This reduces the suction lift required to bring the material from the water surface to the pump. As is shown by the examples cited, this item is an important one and may even exceed the effect of friction in the suction pipe in the consumption of available vacuum. No arbitrary limit other than that due to atmospheric pressure can be placed on the elevation of the pump above water level because of the relative effect of other factors. However, dredge pumps as a rule do not operate effectually if placed more than 6 feet above the surface of the water.

The depth from which a dredge pump can excavate gravel is affected by a number of variable factors. The head required to overcome friction in the suction pipe varies directly with the length of the pipe, the velocity of flow in the pipe, and the percentage of solids in the mixture handled. It varies inversely with the diameter of the suction pipe. The head required to bring the mixture to the surface of the water varies directly with the percentage of solids in the mixture or its specific gravity.

Since each of these factors influences the dredging depth, table 37 has been compiled to illustrate their effect in limiting dredging depth. Combination of conditions are given from A to K in the table. In all combinations, however, it is assumed that the pump is capable of producing 25 inches of vacuum or 28.33 feet of suction head. It is also assumed that at least 10 feet of head will be required to move the material from the deposit into the end of the suction pipe. This is probably a rather conservative allowance, and more would be necessary for coarse or compacted material. In each example it is therefore assumed that there are 28.33 -10 = 18.33 feet of head available at the pump to overcome friction in the suction pipe, to bring the mixture to the surface of the water, and to impart velocity to the material handled. Head for suction lift is eliminated by assuming that the center line of the pump is level with the surface of the water. It is further assumed that a minimum velocity of 5 feet per second is necessary to move sand and that the maximum velocity permitted for gravel is 15 feet per second.

In studying this table, it must be borne in mind that the computations are theoretical, that no head is computed for suction lift, and that the length of the suction pipe is roughly taken as 1 1/4 times the vertical submergence. The vertical submergence shown in each example is a maximum.

TABLE 37.- Maximum dredging depth for various combinations of conditions

	Feet
Assumed vacuum at pump, 25 inches	28.33
Assumed minimum entrance head required at end of suction	10.00
Head available for velocity, friction, and submergence	18.33

Combination and feet of head	Diameter of pump, inches	Diameter of suction, inches	Per-cent of solids	Velocity of discharge, feet per second	Velocity of suction, feet per second	Submergence, feet	Suction length, feet	Total head required	Surplus head	Capacity, cubic yards per hour
A	8	8	15	15	15	33	41			104
					[1]3.5	[2]5.6	[3]8.94	18.03	0.30	
B	8	8	12	10	10	60	75			56
					[1]2.24	[2]8.42	[3]7.05	17.71	0.62	
C	8	8	5	5	5	200	250			11.5
					[1]0.39	[2]12.00	[3]5.00	17.39	0.94	
D	8	12	15	15	6.63	80	100			104
					[1]0.69	[2]13.60	[3]3.00	17.29	1.04	
E	8	12	12	10	6.63	100	125			56
					[1]0.69	[2]14.00	[3]3.36	18.05	0.28	
F	16	16	15	15	15	50	65			419
					[1]3.5	[2]8.5	[3]6.3	18.30	0.03	
G	16	1	12	10	10	80	100			225
					[1]2.24	[2]11.2	[3]4.2	17.64	0.69	
H	16	16	5	5	5	250	315			46
					[1]0.39	[2]15.00	[3]2.84	18.23	0.10	
I	16	20	12	10	7.67	95	120			225
					[1]0.92	[2]13.3	[3]3.84	18.06	0.27	
J	6	6	12	10	10	50	65			31.5
					[1]2.24	[2]7.02	[3]8.45	17.71	0.62	
K	6	8	12	10	5.67	95	120			31.5
					[1]0.51	[2]13.3	[3]3.96	17.77	0.56	

[1]Table 31.
[2]Table 34.
[3]Table 32.

Considered purely as a transporting agent the pump is limited only by the speed permissible in its mechanical construction and the strength of materials of which it and the discharge line are composed. Increased demands for delivery head are met by increasing the speed of revolution and the diameter of the impeller. Obviously these could be increased to such a point that the pressure produced would be more than the construction of the pump would withstand. Centrifugal pumps handling water only may be built for very high pressures, but for such purposes they are usually constructed in stages. That is, two or more pumps or stages are constructed on one drive shaft and within the same casing so that the discharge from the first pump or stage becomes the intake for the next. Single-stage water pumps have been built for heads as high as 400 feet, but these are exceptional. Dredge pumps are seldom built for more than a single stage. Instead booster pumps are added in the discharge line because of simplified construction, reduced pressure on the line, and reduction of internal wear coincident with reduced pressure when handling mixtures of sand and gravel in the water. The construction of modern dredging pumps provides for a range of operating speeds consistent with the safety factor of the strength of material used and the cost of construction. Impellers can be varied in a particular pump as much as 15 percent of their diameter. Obviously a pump of small impeller diameter could be operated at a higher speed and would entail less construction cost than one of large diameter with its more massive rotating parts. Moreover, an increase in speed for any particular pump can be obtained by increasing the drive ratio or changing motors. Increasing the available head by increasing impeller diameter, on the other hand, involves replacing one pump with another. For example, a pump having a 24-inch impeller and operating at 550 r.p.m. will produce a total head of 61.75 feet. (See table 38.) To increase the head to 100 feet an increase to 700 r.p.m. would be necessary and is within mechanical bounds. To retain the same number of revolutions per minute but obtain the increased head would require an increase in impeller diameter to 31 inches. This also is within economical mechanical construction but would necessitate a new pump and increase the headroom required.

On the other hand, if 200 feet of head were necessary the speed of the 24-inch impeller would have to be increased to 1,000 r.p.m., which might be more expensive than changing to a new pump having a 36-inch impeller and operating at a little more than 650 r.p.m.

Any increase, within operating limits, of the head against which a pump must operate results in a loss of volume pumped or capacity unless the pump speed is increased. The efficiency of the pump is thereby lowered. By increasing the speed to retain the same capacity against the higher head more power will be required, but the original efficiency may be retained.

On the other hand, a decrease in the head against which a pump operates results in an increased volume pumped but does not necessarily increase efficiency, because more power is required to move the greater quantity of material pumped.

These apparently antagonistic phenomena are due to the structural characteristics of centrifugal pumps. As previously mentioned the centrifugal pump imparts velocity to the material pumped by revolving the impellor blades within the pump casing. The impeller does not fit the inside of the casing in a tight joint as in plunger pumps. Consequently there is a constant slippage around the impellers through the clearance between them and the casing. Therefore as the delivery head increases, the back pressure or pressure against which the pump must operate increases. As this pressure increases the slippage within the pump increases, hence the loss in volume pumped. If the delivery pressure of a plunger-type pump is increased by closing a valve in the discharge line the pressure will build up to such a point as to exceed the bursting strength of pump or pipe line. On the other hand, if the discharge head on a centrifugal pump is increased by closing a similar valve the pressure will increase to such a point as to cause the slippage around the impellers to equal the volume pumped, and the pump merely rotates the water within its casing.

In a reduction of discharge head, as, for instance, a break in the pipe line, the reduction in pressure reduces the slippage between impeller and casing and thereby increases the volume pumped. This increase in volume demands greater power, and there is therefore a tendency to overload the driving engine which must be guarded against by proper protecting devices.

It is obvious that the performance of an individual dredge pump is influenced and limited by its internal clearance, in other words, by the design of the individual unit. Since this is a matter of the ideas and convictions of the designing engineers of various manufacturers, it is not discussed in this paper.

There are certain general exceptions however which may be noted. For example, a recent inovation is a dredge pump designed to be lowered beneath the water surface with the suction pipe. The effect is to reduce the vacuum necessary to (1) overcome frictional resistance in the suction pipe, (2) bring the mixture of water and gravel to the water surface, and (3) overcome suction lift.

There is therefore a greater portion of the vacuum available to bring material from the deposit to the suction pipe. The head due to submergence also acts to bring material to the suction pipe with this type of pump. The frictional resistance and other factors released from the influence of the pump vacuum are not eliminated, however, but they are transferred to the discharge or transporting function of the pump.

Another application of the centrifugal pump for dredging operations employs the pump to pump water only, at high pressure through a conical nozzle. This nozzle is placed within and near the lower end of the suction pipe. As this high-pressure water is released and rushes up the suction pipe, it creates a vacuum permitting static pressure to force gravel into the end of the suction. It also acts as a conveyor to carry the gravel up the suction pipe to the discharge. In principle this type of dredge is a water ejector on a large scale, or, in other words, another type of submerged pump. A detailed description is contained in Bureau of Mines Information Circular 6580, Methods and Costs of Mining and Preparing Sand and Gravel at the Plant of the Ward Sand and Gravel Company, Oxford, Mich.

AUXILIARY EQUIPMENT

Except in the few instances of self-contained lake- and ocean-going vessels, hydraulic dredges are not self-propelled. Ordinarily dredges operating in rivers, lakes, or along ocean shores must be moved from one digging location to another by towboats or tugs. This is frequently necessary in artificial ponds which have become enlarged by long-continued excavation.

Wherever the distance from digging point to plant is short the dredge pump is called upon to transport as well as dig gravel. As this distance increases auxiliary pumps may be installed in the discharge line. When this is done care is necessary to see that the intake of the booster pump is under some slight pressure from the discharge of the digger. At times, more than one booster has been employed, but ordinarily this increases the cost of power beyond economic limits. In other words, it is usually cheaper to pump short distances, but for long hauls towboats and barges or cars and locomotives are more economical.

Any type of transportation unit may be employed to serve a hydraulic dredge. Usually, however, pump dredges deliver direct to plant through pipe lines or to barges which are towed to the plant. Sometimes, however, dredges are used to dig and deliver gravel to a designated point in the river from which it may be picked up by an auxiliary dredge, clamshell, dragline, or power scraper. In other instances, the digger delivers to storage on the river bank from which other types of equipment carry it to the plant. The transfer from dredge discharge to other equipment must provide some means of dewatering except when a second dredge is the auxiliary unit.

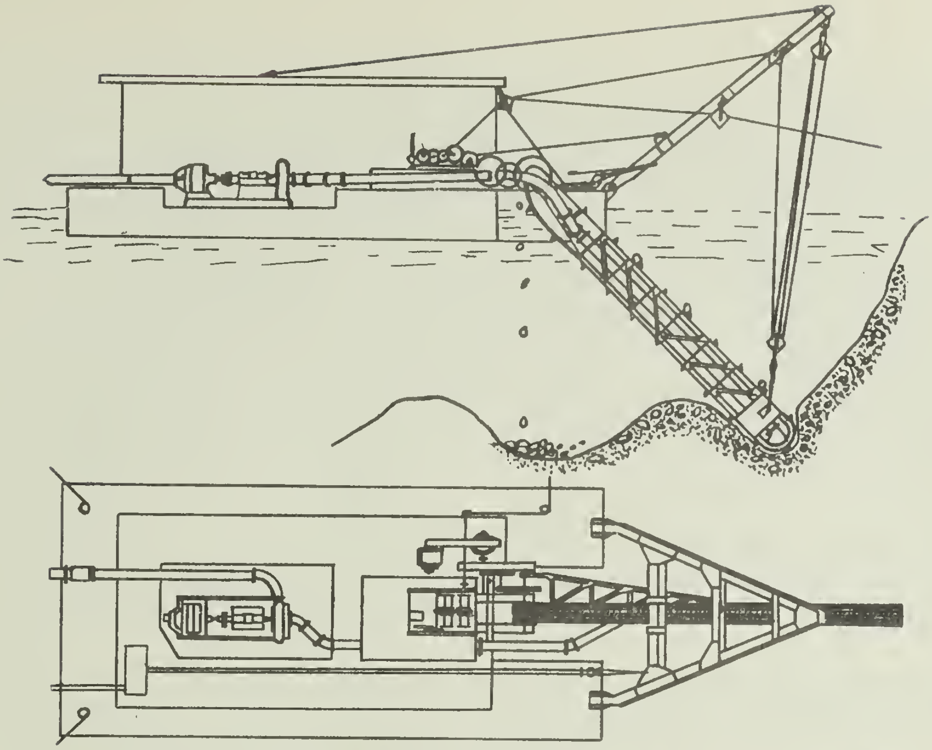


Figure 9.—Plan and elevation of hydraulic dredge with traveling screen.

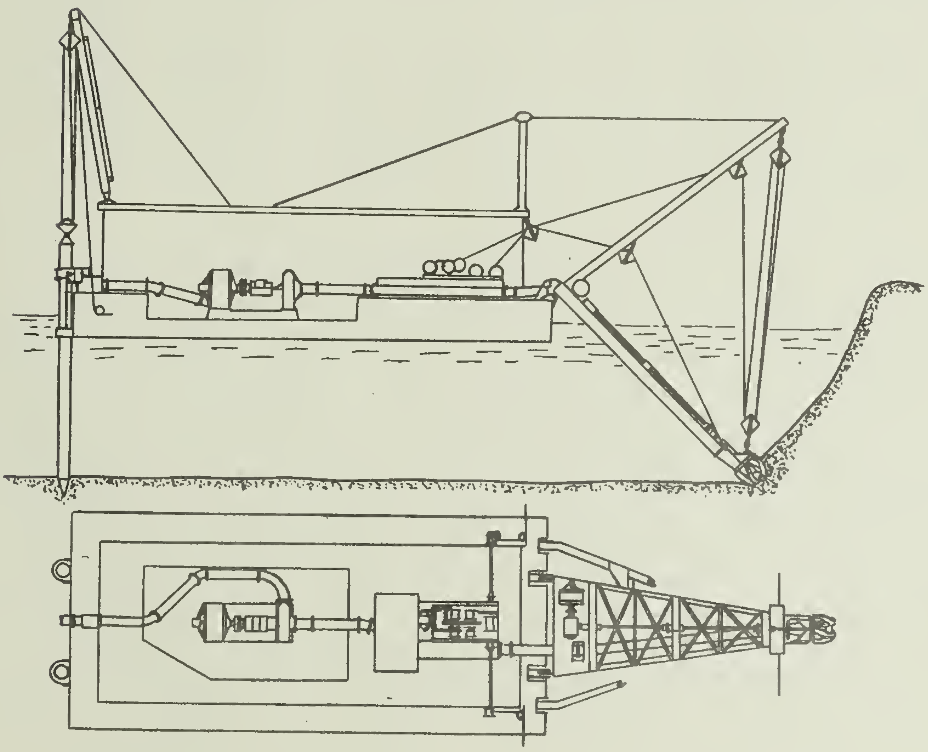


Figure 10.—Plan and elevation of hydraulic dredge with cutter head.

Another type of auxiliary equipment employed by the hydraulic dredge is the traveling screen or rotary cutter head placed at the end of the suction pipe. These aids are used to break up cemented gravel or hardpan and so disentegrate them that the suction can pick them up. In addition to performing this function it also acts as a screen around the end of the suction to prevent the entrance of boulders too large for the pipe.

One type of traveling screen is constructed similar to a double-chain bucket elevator. (See fig. 9.) In place of the buckets heavy steel bars are used, spaced so as to permit the passage between them of only such material as can be handled by the pump. The screens are supported by a boom which also carries the suction pipe. The construction is such that the screen travels downward under the suction pipe, around the lower end over large sheaves, and back up on the upper side of the boom. In passing around the lower sheave the bars break up the gravel so the suction can pick it up.

Another type consists of a rotary head enveloping the end of the suction pipe and driven by a shaft paralleling and attached to the suction pipe. (See fig. 10.) Motive power for the cutter is applied from the dredge deck by auxiliary equipment. The blades on this type of cutter are helical in shape and are spaced so as to prevent oversize material from reaching the suction.

In some instances where the deposit is not densely packed a hydraulic jet is brought down with the suction pipe. Water under high pressure is forced through this jet and against the deposit. Its purpose is to disintegrate the material.

Hydraulic jets also are often used to wash down and cave the bank which the dredge suction is undermining. Without their use dangerous conditions might arise in which large sections caving from the bank might bury the suction line or even cause sufficient surge to swamp and sink the dredge.

No hydraulic dredge pump can by itself start water or gravel up the empty suction pipe. Unlike water, air can be compressed or expanded. Expansion of the air within a confined cylinder by extraction creates a partial vacuum within that cylinder. If one end of that cylinder is open, permitting the entrance of water, which, in turn, is subject to atmospheric pressure, water will enter the cylinder to the extent the air is extracted. A plunger pump with pistons in close contact with the cylinders can extract air from a suction pipe and thereby cause water to flow up the pipe and into the pump. In other words, such a pump can prime itself. The dredge pump on the other hand cannot pump air because of the space between impeller blades and casing. When a dredge pump is revolved without first being filled with water it simply revolves the air within the pump casing. Therefore dredge pumps must have some auxiliary means of priming. A centrifugal pump used for pumping water only is usually provided with a foot valve at the lower end of the suction pipe. This valve permits water to flow into the suction but prevents it from flowing out. A small plunger pump may be connected so as to pump water into the casing and suction pipe of the centrifugal pump and fill them. When so filled the centrifugal pump is primed and when revolved will pump water.

Dredge pumps, however, do not have foot valves because of the abrasion to which they would be subjected when pumping gravel. The usual procedure in priming a dredge pump is to attach an air pump to the pump casing and extract the air from pump and suction pipe. To do this a tight valve must be placed in the discharge line of the dredge pump. Then as the air is extracted it is replaced by water from the submerged open end of the suction pipe. As soon as the pump casing and suction line are filled with water the dredge pump is started and the valve in the discharge line opened.

All types of centrifugal dredge pumps must have some sort of priming device, but the particular kind may vary for different conditions.

In addition to the auxiliary equipment mentioned, hydraulic dredges are frequently equipped with winches, cables, and anchors with which they may be manipulated from side to

side or forward or backward to keep the suction in the most advantageous position for digging. In some dredges these winches and anchors are displaced by wooden or steel spuds. On hydraulic dredges there are usually two spuds used, one on each stern corner of the hull.

The spuds are heavy piles with pointed lower ends which may be raised or lowered by winch and cable. When the hull is brought to the digging position one spud is dropped to the bottom and acts as a pivot around which the dredge is rotated while digging. The position of the hull may be shifted by using the second spud. The hull is then rotated alternately around each spud and thus "walked" to the new position. By alternately raising and lowering the two spuds, the dredge can thus be "walked" across the bottom in any direction.

Hydraulic dredges may be operated by steam, gasoline, Deisel, or electric power or various combinations of these types as prime movers. Steam power requires larger hulls to accomodate the engine and boilers but provides flexibility as excess power or speed may be applied when needed. Boilers must be fired and steam pressure raised before the dredge can operate.

Gasoline or Deisel power plants require less space and therefore smaller hulls and are instantly available for power as soon as put in motion. Variable speed may be applied through gear or other reduction connection between motor and pump. In many localities Deisel power is cheaper than any other, but this depends largely upon local fuel costs.

The continuous operation of dredge pumps makes them peculiarly fitted for connection to any type of power plant which operates at a uniform rate. This includes either gasoline, oil, Deisel, or electric motor. With electric power, variable-speed motors may be direct-connected to the pump shaft or constant-speed motors connected through variable-speed reducers. Primary electric power may be used on a dredge located in an artificial pond in which no extensive shifting from place to place is involved. With such primary power the power cables are usually wound on a reel at the stern of the dredge for flexibility. Where it is necessary to move the dredge frequently from place to place the primary-power plant may be steam or Deisel, driving a generator which in turn supplies electric power to the pump motor and other auxiliary equipment. Such installations however are not common. Ordinarily steam or Deisel power is used direct.

CAPACITY

The capacity of dredge pumps, is really the most difficult question of all, and it cannot be treated otherwise than through empirical figures and rules. Capacity is, of course, a function of the volume of water being pumped and the percentage of solids carried in suspension. Both of these vary continuously, and each depends on a number of factors. The percentage of solids carried in suspension varies with the skill of the operator, the character of the material, the velocity of flow through the pipe line, and the length and character of the pipe line. Naturally, a higher percentage of sand is carried than of gravel, and a higher percentage of material can be carried at high velocity than at low velocity. Moreover, a higher percentage can be carried of a given material at a given velocity when pumping through a short pipe line than when pumping through a long pipe line, especially one having long horizontal stretches of pipe in which the material settles to the bottom of the line and plugs up the pipe. A skilled operator will, of course, feed the material uniformly into the suction and will average a higher percentage of material than an unskilled operator.

The velocity of flow through the pipe line, on the other hand, will vary with the length of the pipe line, the lift, the pump speed, the percentage of solids, and the nature of the solids. Given constant speed, lift, and length of pipe line, the velocity of flow will vary with the percentage of material, being higher when carrying a smaller percentage of material, and vice versa, and being higher for the same percentage of materials which are less sharp and abrasive because of less friction against the sides of the pipe.

Under the circumstances, it is impossible to arrive at any exact formula for determining the output, which can only be arrived at by figuring each case individually and taking into account all the different factors involved.

As a first step in calculating capacity the total head of which the pump is capable must be known. This will vary as the square of the speed for a given diameter of impeller or as the square of the diameter of the impeller for a given speed, and may be roughly expressed by the formula

$$\underline{H} = \underline{V}^2/2g,$$

where $\underline{H}$ is the total head developed in feet, $\underline{V}$ is the velocity in feet per second, and g is acceleration due to gravity or 32.16.

$\underline{V}$ in this case is the peripheral speed of the impeller and may be expressed in feet per second as

$$\text{R.p.m.}/60 \times 3.1416\ \underline{D}/12,$$

where $\underline{D}$ equals the diameter of the impeller in inches.

Substituting this value for $\underline{V}$ in the original formula it becomes

$$\underline{H} = (\text{R.p.m.} \times 0.262\underline{D}/482)^2.$$

This formula is theoretically correct, but in practice the actual head obtained will be 10 to 30 percent higher, depending upon the design of the impeller. A working mean between these variations is usually taken at 20 percent, hence the formula becomes

$$\underline{H} = 1.2\ (\text{R.p.m.} \times 0.262\underline{D}/482)^2, \text{ or}$$

$$\underline{H} = (\text{R.p.m.} \times \underline{D}/1680)^2.$$

Table 28 has been compiled in accordance with this formula to show the head developed by pumps using impellers of varying diameters running at various speeds.

Thus a 24-inch impeller operating at 500 r.p.m. from table 38 gives a head of 51.0 feet.

Referring now to the various combinations assumed for the 8-inch pump in table 36, assume that it had an impeller 24 inches in diameter and was operated at a speed of 535 r.p.m. From table 38 by interpolation the total head developed by the pump would be 58.52 feet. It is true that to produce vacuum this pump must revolve and that the vacuum produced will increase with the speed of the pump up to a certain point. To this extent the speed of the pump determines the vacuum. Dredging pumps must have a certain clearance area between the impellers and the pump casing to permit the passage of gravel. This area permits slippage of the liquid around the impellers within the pump. Thus, when the pump speed is such as to impart the maximum vacuum of which that particular pump is capable any increase in speed does not necessarily increase the vacuum produced.

In the original example it was assumed that the pump was capable of producing 25 inches of vacuum. From table 36 it is apparent that the static head or vacuum available for the several combinations ranged from 11.28 to 19.40 feet. These heads are sufficient to bring sand to the suction and will be enough for uncemented gravel. Therefore the vacuum assumed for the pump is sufficient to bring the sand and gravel to the pump.

The head available due to the speed and diameter of the impellers, less that required to produce vacuum, can then be used for transporting the water, sand, and gravel through the discharge pipe. The available head is then 58.52 - 28.33 = 30.19 feet.

TABLE 38.- Total head in feet developed by dredge pumps.

Speed,	Diameter of impeller, inches											
r.p.m.	12	18	20	22	24	26	28	30	32	34	36	48	60
100	0.51	1.15	1.42	1.72	2.04	2.40	2.78	3.19	3.63	4.10	4.59	8.16	12.75
125	.80	1.80	2.22	2.68	3.19	3.76	4.34	4.98	5.67	6.40	7.18	12.75	20.00
150	1.15	2.58	3.19	3.86	4.59	5.38	6.25	7.18	8.16	9.20	10.33	18.35	28.70
175	1.56	3.52	4.33	5.25	6.25	7.34	8.53	9.76	11.10	12.50	14.00	25.00	39.10
200	2.04	4.37	5.66	6.86	8.16	9.60	11.10	12.75	14.50	16.40	18.35	32.70	51.00
225	2.53	5.80	7.18	8.70	10.30	12.10	14.10	16.10	18.40	20.75	23.20	41.25	64.50
250	3.19	7.17	8.85	10.70	12.75	15.00	17.35	19.90	22.65	25.60	28.70	51.00	79.70
275	3.86	8.68	10.70	12.97	15.45	18.10	21.00	24.10	27.40	31.00	34.80	61.80	96.50
300	4.53	10.30	12.75	15.45	18.40	21.60	25.00	28.65	32.70	36.80	41.40	73.50	120.00
325	5.40	12.10	15.00	18.10	21.60	25.35	29.40	33.70	38.40	43.40	48.75	86.20	135.00
350	6.25	14.05	17.35	21.00	25.00	29.35	34.00	39.00	44.50	50.20	56.25	100.00	156.00
375	7.18	16.10	19.90	24.10	28.70	33.70	39.10	44.80	51.00	57.75	64.50	115.00	180.00
400	8.17	18.40	22.70	27.50	32.70	38.30	44.50	51.00	58.00	65.60	73.50	131.00	204.00
425	9.22	20.75	25.60	31.00	36.80	43.30	50.00	57.50	65.60	74.00	83.00	147.00	...
450	10.35	23.20	28.70	34.80	41.40	48.50	56.25	64.50	73.40	83.00	93.00	165.00	...
475	11.50	25.45	32.00	38.80	46.20	54.00	62.50	72.00	82.00	92.00	104.00	184.00	...
500	12.80	28.70	35.40	42.90	51.00	59.75	69.30	79.70	90.70	102.00	115.00	204.00	...
550	15.45	34.80	43.00	51.80	61.75	72.30	84.00	96.50	110.00	124.00	139.00	...	...
600	18.40	41.30	51.00	61.80	73.50	86.40	100.00	115.00	130.00	147.00	165.00	...	...
650	21.50	48.50	60.00	72.50	86.50	101.00	117.00	134.00	154.00	173.00	194.00	...	...
700	25.00	56.25	69.50	84.00	100.00	117.00	136.00	156.00	179.00	200.00	225.00	...	...
750	28.80	64.50	79.50	96.50	115.00	135.00	156.00	180.00	204.00	...	...	...	...
800	32.60	73.50	90.00	110.00	130.00	153.00	178.00	203.00	...	...	...	...	...
850	36.80	83.00	102.00	124.00	147.00	173.00	200.00	...	...	...	...	...	...
900	41.30	93.00	115.00	139.00	165.00	194.00	225.00	...	...	...	...	...	...
1,000	51.00	115.00	142.00	171.00	204.00	...	...	...	...	...	...	...	...
1,250	80.00	180.00	222.00	268.00	...	...	...	...	...	...	...	...	...
1,500	115.00	254.00	...	...	...	...	...	...	...	...	...	...	...
1,750	156.00	...	...	...	...	...	...	...	...	...	...	...	...
2,000	204.00	...	...	...	...	...	...	...	...	...	...	...	...

1 In general practice maximum pumping efficiency probably does not extend to heads greater than 150 feet, although for convenience the table has been extended to show higher figures.

From table 32 it is seen that 100 feet of 8-inch pipe will require from 7.5 to 10.2 feet of friction head for a velocity of 10 feet per second. Assuming a discharge pipe, level with the pump, it would be capable of pumping through a pipe from 30.19/10.2 x 100 = 296 to 30.19/7.5 x 100 = 402 feet long, depending upon the size and character of the gravel and sand particles.

If the discharge pipe does not need to be longer than 200 feet the friction head necessary would range from 15 to 20.4 feet, and there would be 30.19 - 20.4 = 9.79 to 30.19 - 15 = 15.19 feet to elevate the material. The pump could then pump material at 10 feet per second through 200 feet of 8-inch discharge pipe, the end of which could be 9.79 to 15.19 feet above the center line of the pump, depending on the size and character of the sand and gravel.

Since the sand and gravel composed 10 percent of the material pumped, table 33 shows that the pump would handle 209 cubic feet per minute, or 20.9 cubic feet of sand and gravel.

Converting this to hourly capacity it would be 20.9 x 60 = 125.40 cubic feet, or 46.5 cubic yards.

At 10 percent solids and a velocity of 12 feet per second the pump would deliver through 212 to 262 feet of level 8-inch pipe or through 200 feet of discharge elevated from 1.79 to 9.19 feet. The delivery would be 25.1 cubic feet of sand and gravel per minute, or 56 cubic yards per hour.

Thus it is evident that with a constant pump speed an increase of 2 feet per second in velocity has increased capacity but has cut the length of level discharge pipe an amount ranging from 84 to 140 feet, or with a constant length (200 feet) of discharge it has cut the elevation to a maximum of 1.79 to 9.19 feet.

In other words, to maintain the same length of level discharge pipe an increase from 10 to 12 feet per second in velocity and consequent capacity would require that the speed of the pump be raised to 587 r.p.m. At this speed the elevation of the end of the discharge pipe, if 200 feet long, could be increased to a maximum of 13.72 to 21.12 feet.

As is evident from the foregoing discussion, it is impossible to present a table of pump capacities unless it is confined to certain definite values for the different variables. However, it is believed that by the use of the tables given herein an operator can apply the values coincident with his local conditions and answer his problems.

A rough approximation of pump capacity, in which the ratio of solids in the discharge is assumed as 10 percent, the velocity of discharge as 12 feet per second, and the total head to be within reasonable limits, may be made as follows:

The capacity in cubic yards per hour equals seven eighths the square of the pump diameter in inches.

In the example cited (above) the 8-inch pump was calculated to have a capacity of 56 cubic yards per hour. If this rule is applied, 8 x 8 x 7/8 = 56 cubic yards.

Working Capacity

The previous calculations, while based upon experimental data, should nevertheless be classed as theoretical and will probably represent what may be termed "average conditions." They can easily be greatly exceeded in handling loose, fine sand and, on the other hand, may be greatly reduced in attempting to recover coarse or partly cemented gravel.

In any case the theoretical capacity should be reduced by 25 percent to obtain a safe working capacity.

CLAMSHELL DREDGE

The term "clamshell", as applied to a dredge, specifically refers to the use of a clamshell bucket swung from the boom of a crane mounted on a floating hull. The term, however, is commonly used to cover the same type of excavator using an orangepeel or even in some cases a dragline bucket. The general term for this type of excavator is the "grapple" dredge.

Fundamentally the clamshell dredge consists of a barge upon which is mounted an excavator crane. The crane may be the mobile land type temporarily placed on the barge for use as a dredge, or it may be dismounted from its chassis and permanently fixed on the barge. In other cases the crane element is built integrally into the hull construction. Either the clamshell, orangepeel, or dragline bucket may be used, regardless of the type of mounting.

The barge or scow on which the crane is mounted may serve as a base only, or the crane may be placed at one end and the balance used as cargo space for gravel loading or temporary storage. Some producers install machinery on the hull for either partial or complete treat-

ment of the excavated sand and gravel. (See fig. 11.) This type of dredge as used for sand and gravel excavation is seldom self-propelled, although for river and harbor work the hull often carries driving engines as well as cargo space.

The clamshell dredge may then perform the single function of excavation; it may combine excavation with storage; it may combine excavation with partial or complete treatment; or it may combine excavation with transportation.

Clamshell dredges are essentially submarine excavators but may be used to excavate material to a limited extent above their floating base. As an example, the dredge may remove a thin overburden from a low bank and cast it to waste in the water. It can then remove the gravel from above and below water level and load it either into barges moored alongside or to cars running on tracks laid on the land surface beyond the stripped area.

Like its land counterpart, the clamshell dredge depends upon the weight of the bucket and the shape of its cutting edges to penetrate and dig gravel. It has no means of forcing the bucket into the deposit except to the limited extent possible when using a dragline bucket. The impact of the bucket on the deposit is less in submarine excavation, however, because of the buoyant effect of the water. Hence the dredge has more difficulty in penetrating compacted gravels than a crane operating in a dry pit. With this exception the dredge is subject to the same difficulties in excavating hardpan as the crane.

In excavating submerged deposits containing boulders, the operator must spot the bucket blindly because of his inability to see below the water surface. Hence more time is required than in similar dry excavation.

Mounted on an unstable floating base, the clamshell dredge may not have the lifting power of similar land equipment. The lifting power is limited by the buoyancy of the barge mounting. The action of the dredge may be compared to the mechanics of a simple lever in which the end of the boom is the point of power application, the center of gravity of the dredge the point of lift, and the base of the crane the fulcrum. As the lever arm or lift increases, the fulcrum is forced deeper into the water. When digging to either side this tends to careen the dredge. Hence the designer must resort to marine-engineering principles in addition to those required for designing land equipment in maintaining stability.

The dredge in which the boom and excavating equipment are integral with the hull is usually equipped with spuds. When dropped to the bottom and forced into the bed they act as legs and stablize the hull against careening.

When digging at excessive depths it is impossible to use spuds, and the stability of the dredge and its lifting power are entirely dependent on the buoyancy of the hull. When dredge hulls are properly designed to fit the operating machinery, the lifting power will equal that of similar land equipment.

When dragline buckets are used on this type of dredge additional strain is thrown upon the spuds by the drag of the bucket. This is usually met by supplementing the spuds with cables and anchors.

Clamshell dredges are probably in greater use as excavators for river channels or underwater foundations than for commercial sand and gravel production, although their use for the latter is not at all unusual.

The cycle of operations is similar to that of the excavator crane but is usually of longer duration. There are various reasons for this. Both hoisting and lowering speeds are reduced when the bucket is submerged in water. Swing acceleration is reduced for the same reason, although deceleration may be increased. Moreover, the time required to hoist and lower the bucket is usually longer with dredges because of their common use for deeper excavation. However, this does not always follow. In removing gravel from the same submerged depth, the operating cycle of the land crane may be greater than that of the dredge because the elevation of its working base is higher on the bank and because it must hoist its bucket

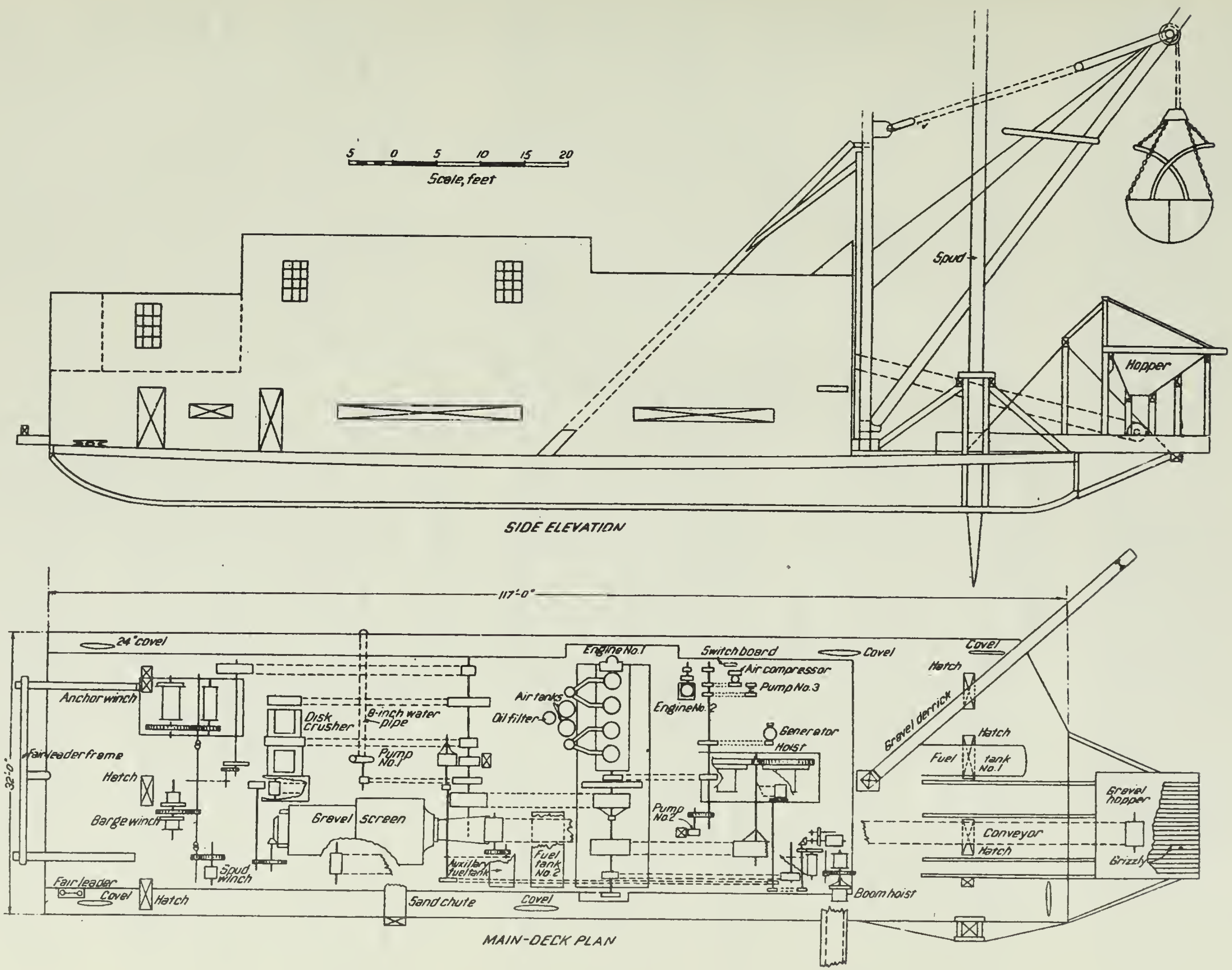


Figure 11.—Side elevation and main-deck plan of clamshell dredge.

to a car on the bank. The dredge, on the other hand, may need to hoist only to clear the side of the barge.

Because of their ability to take succeeding bucket loads from independent points irrespective of any regular scheme of excavation, clamshell dredges operate to better advantage than other types of dredges in river deposits containing quantities of sunken logs and other debris. In fact this has often been the deciding factor in determining the dredge to use on this type of deposit.

Structural Limitations

Clamshell dredges operate only from the surface of a body of water. Used principally for submarine excavation they can remove material from only a limited height above the water surface.

Owing to the instability of their floating base they cannot ordinarily operate with as low a boom angle as can the land crane. For this reason their operating reach may be somewhat curtailed, although their dumping height may equal that of a similarly equipped land crane.

For the same reason the tendency to overturn is greater with the dredge than the crane unless the dredge is equipped with spuds.

The depth from which a clamshell dredge can excavate, however, is limited only by the economic factors involved in the lengthened operating cycle. For this reason the clamshell is capable of excavating from greater depths than any other type of dredge.

The boom may be capable of complete revolution through 360°, as in the case of temporarily mounted land equipment, or the movement may be confined to only such portion of the circle as may be necessary to load barges moored alongside or to reach the hold or receiving hopper serving the treatment machinery on the dredge itself.

Clamshell dredges may be operated with any convenient type of power, either steam, gasoline, Diesel, or electric. Like the shovel and dragline, their intermittent action does not lend itself to economic consumption of electrical power.

Service Equipment Required

Clamshell dredges must be equipped with some sort of apparatus to hold them in position and resist the stresses set up while digging. These are supplied by winches with cables and anchors, or spuds, depending upon the conditions under which the dredge is operating. When spuds are used there are usually 3, 1 at each bow corner of the hull and 1 in the center at the stern. The dredge position is shifted by walking on the 2 forward spuds.

The great majority of dredges of this type are not self-propelled and must therefore depend upon some type of transportation unit. For river and harbor work, self-propelled, sea-going hulls with cargo hoppers are often used. The type of transportation unit in most common use is the towboat and barge. In ordinary practice the empty barge is moored alongside the dredge; the bucket is swung over the barge and dumped. Usually winches are provided on the dredge by which the barge can be moved forward and backward while loading to distribute the load evenly over the cargo space.

In some installations the clamshell dredge dumps its load to a hopper covered by a protecting grizzly constructed either on an auxiliary barge or on the dredge itself. The sand and gravel are then picked up from the hopper by a dredge pump and conveyed through pipe lines to the treatment plant. In other installations the conditions are reversed and the excavation is done by hydraulic dredge which pumps to submarine storage near the plant; from there the gravel is picked up by a clamshell dredge and elevated to a hopper or other equipment feeding the plant.

In installations in which the digging equipment is mounted on the end of the barge, the center and other end of which are fitted for cargo carrying, this type of construction has two functions. In one, the dredge is towed to the deposit, loads its cargo capacity, is returned to the plant or unloading site, and there uses its excavating equipment to unload itself. In the other, the dredge remains at the digging site and loads barges as they are brought to it. Between visits by the towboat, in case of unusual delay, it may continue to dig gravel and load its own hold. Upon arrival of a fleet of empties it can then unload its hold to them.

In more elaborate types of dredge which either partly or wholly treat the sand and gravel, provision must be made for installation of this equipment and the power to operate it. This involves careful hull design and distribution of the various units to maintain equilibrium under all operating conditions.

Capacity

The capacity of a clamshell dredge is subject to the same variable factors as that of similar land equipment, in addition to variables pertaining to marine operation, such as storms, floods, leakage of hulls, etc.

When it is used to excavate from excessive depths, its capacity is reduced by the lengthening of its time cycle due to that depth.

Rated or theoretical capacity for a single unit size cannot be computed because there is no common base from which to start calculations. Whereas the shovel or dragline has a fairly limited uniform starting and stopping point for each digging cycle, the clamshell dredge is constantly changing its hoisting, lowering, and swinging range as material is dug.

Working capacity may be calculated approximately for operating conditions, at each particular site, but this requires data which vary with each location. Generally it may be said that the working capacity of a clamshell dredge will compare favorably with that of a crane or dragline operating under similar conditions as to depth of digging and character of material being handled.

With the clamshell dredge as with other types of equipment, the skill and efficiency of the operator is a large factor in capacity. This is probably of even greater moment with the dredge than with the crane. The operator must constantly keep in mind the danger of overturning the dredge. He must spot each bucket blindly, since he cannot see below the water surface. If the deposit is fouled with sunken logs and other debris, he must be expert in being able to dig around and remove them, or, if too large to remove, in obtaining a maximum of material from their vicinity.

The time required to spot a bucket for dumping will be reduced in the operation of a clamshell dredge because of the larger transportation unit. On the other hand, care must be exercised to load barges equally over their whole area. Otherwise they may become dangerously unbalanced on one side or end.

LADDER DREDGE

The ladder dredge was originally developed as a tool to excavate placer gold deposits. These deposits seldom contain more than a dollar and often as low as 10¢ in gold per cubic yard of gravel, hence the volumetric ratio of gold to gravel is very small. The cost of transporting the excavated material to a shore treatment plant, where the gold could be extracted, and then disposing of the great volume of gravel, which had no commercial value to the placer miner, was too great for economic operation. This type of dredge, therefore, was

from necessity developed to dig, treat, and dispose immediately of huge quantities of material with as little handling and in as short a time as possible. To reduce labor costs the design embodied complete mechanization. In addition, since placer deposits are often extensive, although comparatively shallow and narrow, the unit must have operating mobility although it does not require the ability to propel itself over long distances. Ladder dredges for placer mining evolved into huge, powerful, self-contained machines requiring a large initial investment but capable of low operating costs.

Since the recovery of commercial sand and gravel combines the necessity of handling large tonnages at low cost and the immediate disposal of waste, this type of dredge admirably solved the problem for the gravel producer where local conditions permitted its use. The ladder dredge has therefore become an important tool in gravel production.

The design of hull and digging equipment has followed closely that for gold dredges. The machinery for treating the gravel has been altered to fit the needs of the gravel producer. The original idea of a big, powerful unit has remained, and this type of gravel dredge while built in various sizes and capacities, still remains a tool for large rather than small production.

Ability to dig and treat large quantities at the excavation site so that only marketable material needs to be transported enables the ladder dredge to operate at maximum distances from distributing points.

Ladder dredges do not have storage space aboard, except as it may be needed to provide even flow between the units of the treatment equipment.

In the absence of self-propelling machinery, except such as is needed to shift position as excavation progresses, they do not perform the function of transportation. Neither is this type of dredge designed for excavation only.

In combining excavation and treatment functions these dredges may be designed for either partial or complete treatment. In either case the excess fine sand and silt are eliminated. When designed for only partial treatment the dredge separates the sand from the gravel and two products only are made. Otherwise both sand and gravel are further washed, crushed, and sized for shipment as finished products.

Neither the design nor the construction of ladder dredges is standardized. Certain component units follow standards developed by experience, but the complete assembly differs with each dredge. Because of this individualistic design they must be assembled at the site at which they are to be used, or at a shipyard from which they can be floated to their destination.

Although frequently used in ponds of their own making in placer mining, ladder dredges are less frequently so used in gravel production probably due to the high initial cost and the scarcity of sufficient workable area in close proximity to large markets. Because of their size and unsuitability to withstand storms and heavy seas, their use has been confined largely to river deposits or well-sheltered lake or ocean beaches.

Ladder dredges are best adapted to removing horizontal slices from submerged deposits.

Dredge hulls may be of timber or steel construction. They are rectangular in shape with vertical sides and vertical or overhanging bow and stern. At the bow the hull is cut by a central well extending a considerable distance amidships. In plan the hull is a rectangle with the bow split to form the arms of a two-pronged fork.

The operating principle, insofar as it concerns excavation, is that of an enlarged and powerful bucket elevator. The digging element consists of the elevator supported by and revolving around a structural-steel "ladder" or boom. One end of the ladder is hinged on the dredge hull in such a position that the other end is free to be lowered or raised through the well in the bow. When in operation the free end of the ladder and elevator is lowered to contact the gravel in the stream bed. It may be raised clear of the water for inspection or repairs or for change of dredge location.

The structural-steel ladder may be a single rigid unit hinged at its upper end or it may be built in two parts, the upper portion integral with the superstructure and the lower portion hinged at the deck line. The lower end in either case is supported by a cable reeved through a series of multiple blocks hung from a bow gantry usually built in the form of an A-frame straddling the central well in the bow. By means of a hoist operating the cable and blocks the ladder may be raised or lowered at will.

At either end of the ladder is a pulley or spool around which the bucket assembly revolves. The spool at the upper end of the ladder, called the "upper tumbler", is designed as a sprocket to act as the drive for the bucket line. That at the lower end, called the "bottom spool", acts merely as a guide for the bucket line but must be of unusually heavy construction to withstand the abrasion to which it is subjected. While digging, the lower end of the ladder rests on the stream bed, the whole assembly inclined at an angle varying with the depth of the digging and the ladder length. The maximum angle of inclination is 45° below the horizontal and the buckets travel upward on top of the ladder and downward on the under side.

The design of the bucket line varies in detail with different manufacturers. There are two general types -- the slack line and the tight line. In the former (fig. 12) the total length of the bucket line is appreciably greater than double the ladder length. This permits the bucket line to hang in a slack loop on the under side of the ladder. In consequence, several buckets simultaneously contact the deposit in a more or less horizontal line. Advocates of this design claim that in deposits containing boulders the flexible bucket line allows more digging time for each bucket resulting in a higher percentage of capacity load for individual buckets.

In this type of construction the buckets are fastened to two chains, the links of which engage in sprockets on the upper tumbler. The buckets may be spaced on the chain at any desired pitch or may be continuous, each pinned to the next and forming a link in the chain.

In the tight line design (fig. 13) the buckets are continuous. The bucket line exceeds twice the ladder length only enough to provide flexibility. In this arrangement the digging is done as each bucket rounds the bottom spool.

Each type of design has its advocates and critics.

On some dredges the upper end of the ladder is hinged close to the bow so that the lower end is at all times in advance of the hull. In others the ladder is swung some distance back of the bow. In shallow digging the point of excavation may then be in advance of the hull, but as depth increases and the ladder is lowered this point retreats to a position vertically below the hull. The greater forward extension allows more room on the hull for treatment machinery and permits undercutting and caving a bank at a safer distance from the dredge.

The ladder dredge excavates by forcing the buckets into the deposit, cutting successive slices as each revolves around the lower spool. In loose sand the ladder is suspended on the hoist cable, and the buckets pick up the gravel as it caves to them. In stiff clay or cemented gravel direct force may be applied to the cutting edges of the buckets by lowering the ladder and allowing its weight to bear. Because of the weight, power, and saw-tooth cutting action of the bucket line surprisingly tough or compacted material can be excavated.

The ladder dredge is at a disadvantage in deposits containing appreciable amounts of boulders larger than can be carried in the buckets, or wherever the deposit is contaminated with sunken logs. With an excess of large boulders these collect in the pit formed by the digging buckets as they are freed from the finer material. When a sufficient number accumulate they cause trouble by preventing the buckets reaching virgin material or by stopping the bucket line. The ladder must then be raised and the dredge swung to a new position. Where large sunken logs are present the buckets catch under them and stop the line. This type of dredge has no means of picking up boulders or logs and moving them to one side as has the clamshell and dipper dredge.

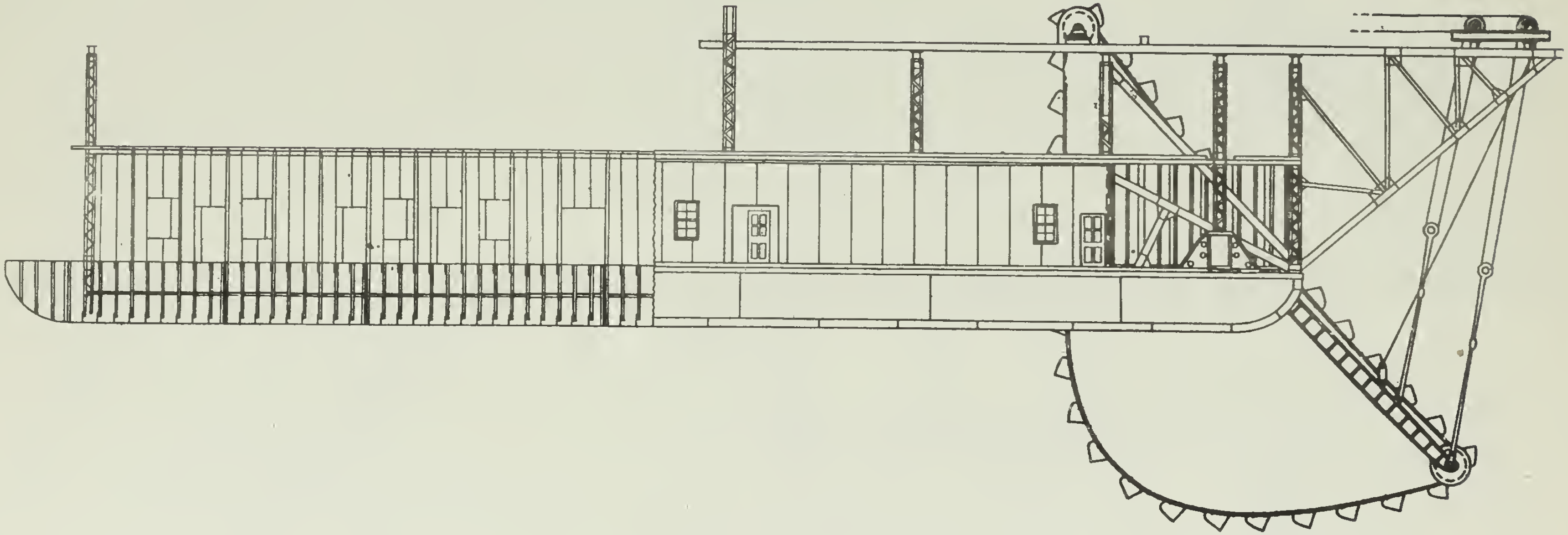
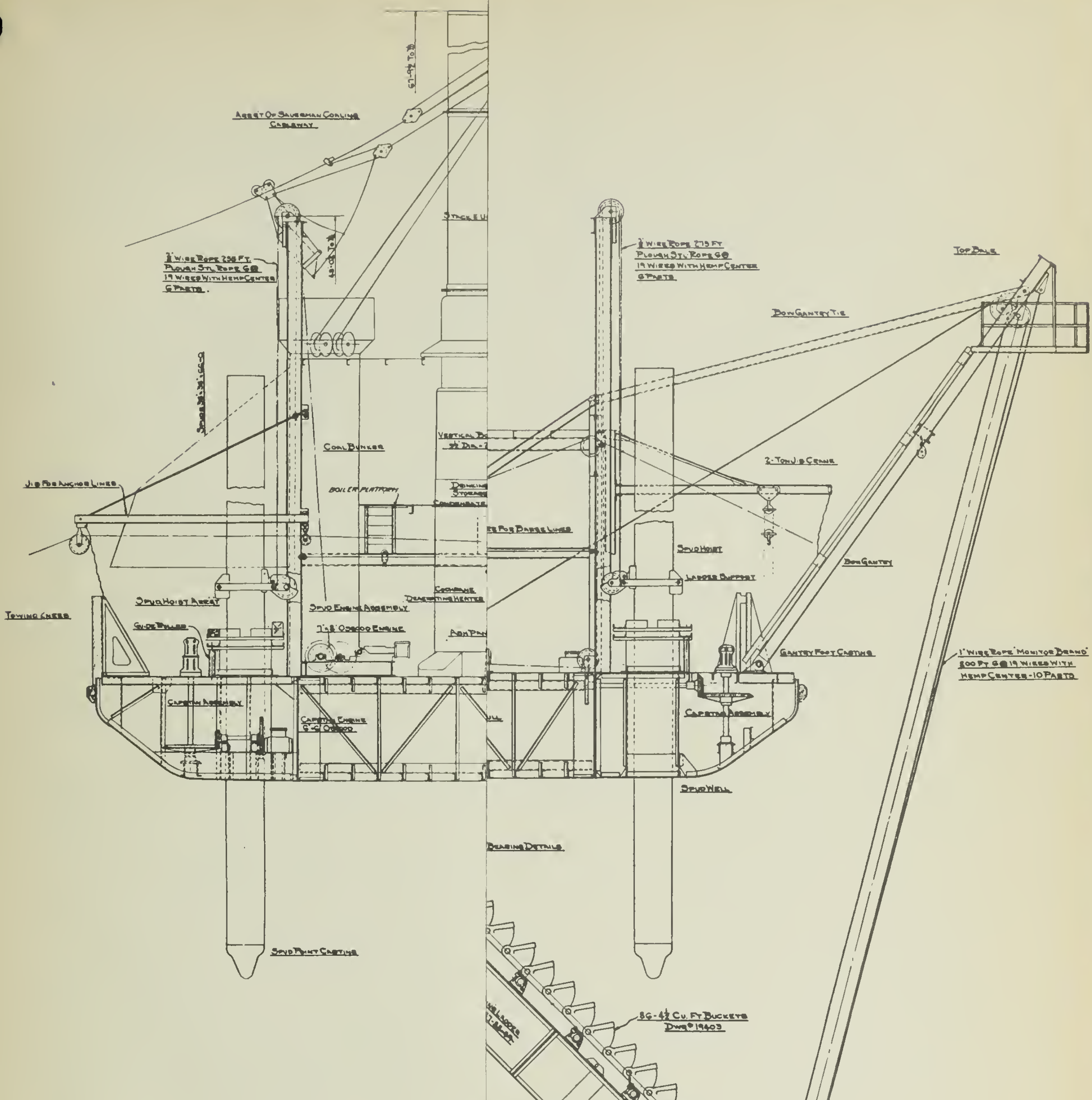


Figure 12.—Side elevation of dredge showing slack bucket line.


Ass'y Of Sauerman Coaling Cableway
$\frac{3}{4}$" Wire Rope 295 Ft. Plough Stl. Rope 6@ 19 Wires With Hemp Center 6 Parts.
Stack & U
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Boiler Platform
Jib For Anchor Lines
Towing Chess
Spud Hoist Ass'y
Guide Roller
Spud Engine Assembly
7"x8" Osgood Engine
Ash Pan
Capstan Assembly
Capstan Engine 6"x6" Osgood
Cochrane Deaerating Heater
$\frac{3}{4}$" Wire Rope 275 Ft Plough Stl. Rope 6@ 19 Wires With Hemp Center 6 Parts
Top Bale
Bow Gantry Tie
2-Ton Jib Crane
Spud Hoist
Ladder Support
Bow Gantry
Gantry Foot Casting
1" Wire Rope "Monitor Brand" 800 Ft 6@19 Wires With Hemp Center - 10 Parts
Capstan Assembly
Spud Well
Spud Point Casting
Bearing Details
86-4½ Cu. Ft Buckets Dwg# 19403
Bottom Bale
Bottom Spool
35'-6" Below W.L.

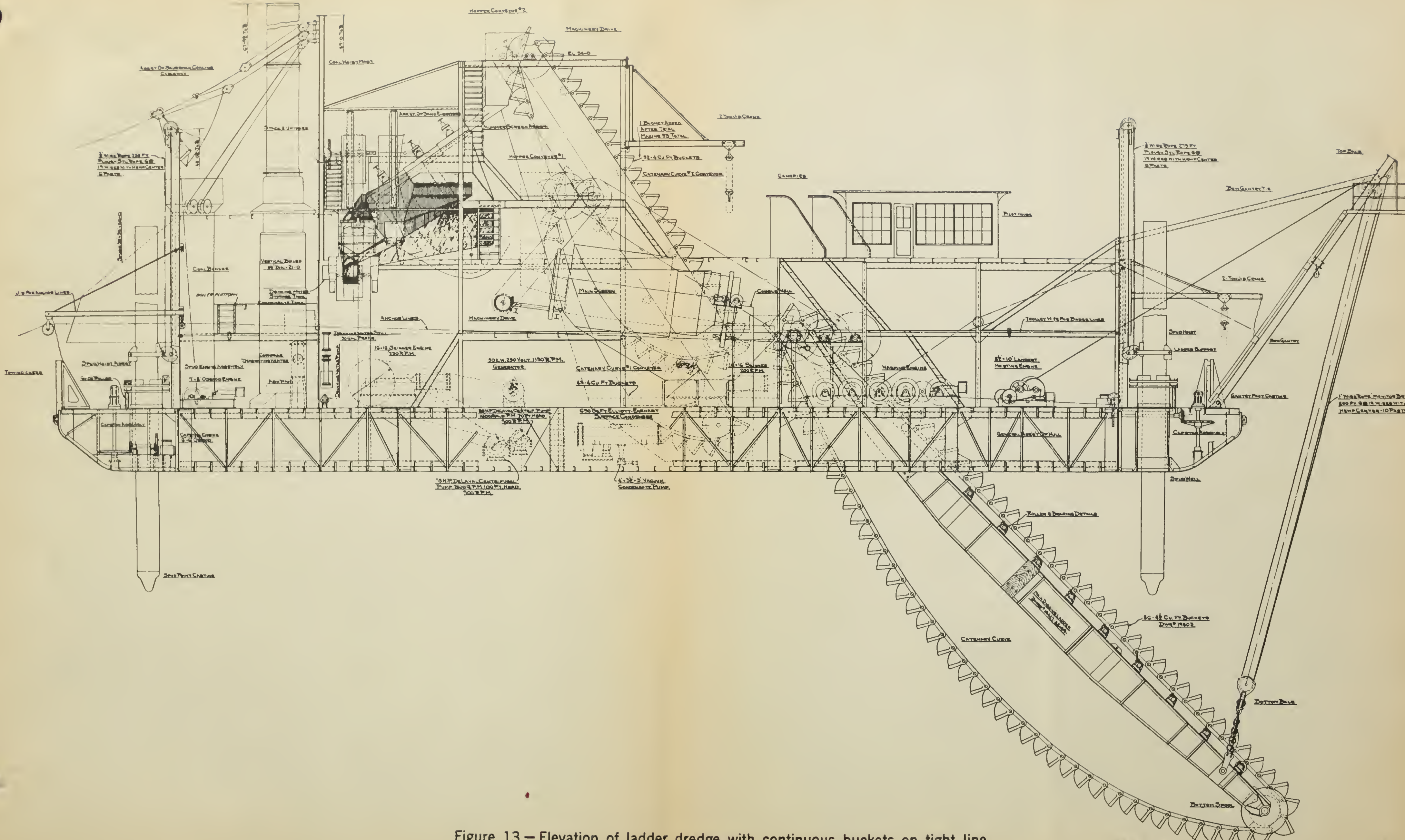

Figure 13.— Elevation of ladder dredge with continuous buckets on tight line.

To provide against damage when boulders or logs are encountered, suitable disengaging equipment is sometimes provided, so that when a pull beyond the safe limit is encountered the driving mechanism is thrown out of gear and the bucket line stops. Skillful operators can usually work around such situations by raising and lowering the ladder while it is in operation.

Structural Limitations

Ladder dredges, because of their heavy and powerful digging units and complement of washing and screening machinery, require large hulls of greater draft than clamshell or hydraulic dredges. Consequently they cannot be moved from place to place as easily and require deeper water for operation.

Having no propelling machinery, they cannot move over extended distances by their own power. The usual complement of winches and cables enables movement while digging, but in order to change from deposit to deposit they must rely upon towboats or tugs.

The depth to which a dredge can dig depends entirely upon its individual design. Depth ranges do not follow either size of bucket or length of spud. Any ladder dredge can dig from the minimum depth at which the hull can be maneuvered to the maximum permitted by the length and inclination of its ladder. The length of the ladder on any dredge is designed to suit the conditions under which that particular unit may be operated. Thus a machine wielding a 2 1/2-cubic foot bucket line may be designed with a short ladder for shallow excavation or a long ladder for deep digging. Similarly, the 16- or 21-cubic foot dredge may have a short or long ladder. Either size may also be built for low or high bucket speeds. Excavation depths reach 90 feet and are commonly 30 to 50 feet below water line.

Where a dredge is required to undercut and cave a bank, the location of the ladder hinge on the hull is important. A short ladder hinged on the bow may excavate a comparatively high bank safely. On the other hand, a longer ladder hinged farther amidships may have an equal forward reach at greater depth. In either case, safety in bank caving requires a hydraulic pump and jet to cave the upper part of the bank.

Ladder dredges discharge the products made by gravity flumes, conveyor belts, or other means, to barges moored alongside.

Ordinarily the upper end of the ladder is carried high on the hull superstructure so that excavated material feeds by gravity to the washing and screening equipment. In some cases, however, the discharge end of the ladder is kept low for hull stability, and lighter auxillary elevators are employed to carry the material to the height desired. (See fig. 13.)

The ladder and bucket assembly is capable of vertical motion only. In order to change the digging point laterally, therefore, the whole dredge must be swung. Because of the excessive stress to which a long ladder would be subject if the dredge was moved while excavating, the usual practice is to raise the ladder clear of the deposit while the dredge is being shifted. For the same reason ladder dredges are held in position by spuds rather than anchors attached to cables and winches. There is too much flexibility in the latter type of anchorage alone to provide the necessary stability for the thrust of the bucket line.

Service Equipment

Ladder dredges depend upon other equipment for transportation. The most common form of such service units are the towboat and barge. Having no storage space aboard, the dredge is wholly dependent upon the transportation unit for capacity production. If the length of haul and transportation units are so coordinated as to have empty barges at the dredge at all times the latter can usually deliver its designed capacity.

By the use of winches mounted on the dredge hull in suitable locations, the dredge can be shifted from one digging position to another through cables and anchors. Ladder dredges are held in digging position by means of spuds supplemented by anchors and cables. Spuds may be located at the bow or stern as conditions require but are limited to 1 or 2 at the stern for small dredges, while those of large capacity may have 4 - one at each corner.

Other winches are provided for shifting barges while they are being loaded.

Ladder dredges are essentially self-contained digging and treatment plants. As such, they operate at a distance from any source of power. For this reason they usually carry their own power plant aboard. Power may be either steam, gas, oil, or Diesel engine, or any of these may be used as the prime mover to generate electric power. Electric power from a source on shore may be used where the dredge is not required to move long distances. As this seldom occurs in sand and gravel excavation such dredges generate their own power. The size of the power unit supplied to any dredge is a matter of individual requirements and cannot be tabulated by dredge size or capacity.

The usual skiffs or motor tenders are necessary to transport men and supplies to and from shore and to place and move anchors.

Ladder dredges are equipped with washing and screening equipment, but since this paper deals with excavation a discussion of such units will be taken up in a following publication.

Capacity

The capacity of a ladder dredge depends upon the size of the buckets, their spacing on the line, the speed at which they travel, and the ability of the operator to keep them coming up with a maximum load without stalling. The size and spacing are fixed for each installation, and usually the speed is also fixed for each particular dredge. However, these are not standard with different dredges, hence two units with the same size buckets may be capable of totally different capacities due to variations in speed or spacing. Moreover, the skill of the operator in handling a specific unit may influence the capacity by 100 percent or more. For these reasons exact calculations as to capacity cannot be made except for individual dredges for which all the necessary elements are known. If bucket size, spacing, and speed are known the theoretical capacity is easily computed, but the average working capacity is seldom more than 50 to 60 percent of theoretical. In ideal conditions, however, these ratios may be exceeded.

Buckets as furnished by builders range from 2 1/2 to 21 cubic feet in size. Speeds range from 60 to 90 feet per minute corresponding to the dumping of 15 to 40 buckets per minute. Spacing or pitch in lines of the continuous-bucket design depends on the size and design of individual buckets, although the variation in pitch does not increase directly with bucket capacity. In noncontinuous bucket lines the pitch is a matter of the individual preference of the designer or operator.

As an example of capacity calculations assume a dredge is fitted with 2 1/2-cubic foot buckets spaced 2 feet apart and traveling at a speed of 60 feet per minute. Such a dredge theoretically should deliver 2 1/2 cubic feet of material each 2 seconds, or 167 cubic yards per hour. However, it is seldom, and then only for short periods, that each and every bucket comes up completely filled, even in the most favorable digging conditions. Moreover, dredges seldom operate over 80 percent of the possible working time. Hence, calculations for working capacities should be based on 50 to 60 percent of theoretically calculated figures.

As an indicator of working capacities of various sized dredges, table 39 has been compiled from reports of operations from various sources. The capacities listed are for actual excavation under what may be termed "average working conditions."

TABLE 39.- Working capacities of ladder dredges[1]

Bucket capacity, cubic feet	Dredge capacity, tons per hour From-	To-
1.5	38	75
2.5	63	160
3.0	112	200
3.5	45	135
4.0	188	260
5.0	260	320
5.5	282	...
6.0	188	360
7.0	263	358
7.5	216	475
8.0	450	563
8.5	450	...
9.0	450	968
9.5	412	...
10.0	512	900
13.5	640	800
15.0	750	950
17.0	860	...
18.0	900	1,200
21.0[2]	450	600

[1]Figures compiled from operating records of gold dredges, 1923-33.
[2]Pitch of buckets, 5 feet.

Hennen Jennings[3] gives several tabulations of the performance of gold dredges in Montana from which table 40 is abstracted.

From this calculation it is apparent that the actual tonnage dug by each dredge was considerably less than the theoretical tonnage even when corrected to the actual average speed of the bucket line. This discrepancy must then be due to partly filled buckets. Calculating the actual tonnage produced against the theoretical at the average speed, dredge, no. 1 worked at 66.4 percent capacity, no. 2 at 61.2 percent, no. 3 at 53.8 percent, and no. 4 at 64.0 percent capacity. In other words, a reduction of 40 to 50 percent below theoretical capacity is indicated in these examples due to partly filled buckets. If actual tonnage was calculated against theoretical tonnage at the designed speed the reduction would be still greater. However, it must be borne in mind that these dredges were digging placer gold, and in so doing greater care was used to clean the bedrock thoroughly than would be exercised in digging gravel for commercial purposes. This cleaning of bedrock probably accounts for the low efficiency in filling buckets.

Since this careful clean-up is unnecessary in gravel excavation, it is estimated that working capacity can be calculated fairly accurately as 60 percent of the theoretical computed from speeds and bucket sizes.

3 Jennings, Hennen, History and Development of Gold Dredging in Montana: Bull. 121, Bureau of Mines, 1918, pp. 63.

TABLE 40.- Performance data of four electric gold dredges in Montana

Item	Dredge no. 1	2	3	4
Date built	1908	1908	1906	1911
Ladder length ... feet	69	80	100	116
Digging reach below water ... do.	30	35	45	55
Average depth dug ... do.	22.1	28.1	40.8	45.3
Type of bucket-line drive	Belt	Belt	Gear	Gear
Power on bucket line ... hp.	100	100	150	550
Number of buckets	60	80	80	80
Bucket pitch ... inches	32.75	32.75	32.75	40.0
Bucket capacity ... cubic feet	7½	7½	9½	16
Buckets per minute, theoretical	16	15	15	20
Buckets per minute, average operating	15.75	12.98	14.15	18.62
Operating time (percent of total)	71	67	65	65
Cubic yards dug per hour	174	132	161	420
Cubic yards dug per bucket	.18	.18	.19	.38
Total operating cost, cents per cubic yard	5.66	6.94	6.75	4.85

Author's calculations from the above data

Item	1	2	3	4
Bucket speed, theoretical ... feet per minute	43.7	41.0	41.0	66.6
Bucket speed, average operating ... do.	43.0	35.4	38.6	62.0
Cubic yards per hour (full buckets):				
At theoretical speed	266	250	317	710
At operating speed	262	216	299	656

DIPPER DREDGE

The dipper dredge was developed as an excavation tool for ship-channel and other submarine excavation. It has been employed to only a limited extent in sand and gravel excavation. Although other types of dredges are capable of greater capacities, the dipper dredge has distinct advantages in recovering material from certain types of deposits.

In its essential features the dipper dredge is a power shovel mounted on a floating hull. (See fig. 14.) While the shovel is limited to dry and the dipper dredge to wet excavation; both wield a dipper on the end of a dipper stick mounted on a swinging boom. Aside from this similarity, the two units have little in common, either in structure or operation.

Like the shovel, the dipper dredge performs the single function of excavation. It neither transports nor treats excavated material.

The shovel is self-propelled and excavates material lying above its operating base. The dredge, on the other hand, is not self-propelled and excavates principally from below the surface of the water on which it floats. However, just as a shovel can dig a short distance below its base, so the dredge can remove banks extending a short distance above water line.

Structurally the dipper dredge consists of a rectangular, steel or wooden hull with vertical sides and vertical or overhanging bow and stern. At the bow a reenforced wood or structural-steel boom is mounted on a base capable of swinging horizontally through an arc of 180°, mo e or less. The boom angle may be fixed between 35° to 45° above the horizontal, or it may be adjustable by the proper arrangement of cable and blocks. The boom supports the

dipper stick and dipper. On dipper dredges, however, both boom and dipper stick are longer and of heavier construction than on a shovel wielding the same size bucket.

The dipper dredge is a heavy, powerful machine capable of tearing loose heavy clay, cemented gravel, and even solid but comparatively soft rock such as shale which could not be removed by other types of dredges. It is also efficient in deposits containing a large percentage of boulders or those contaminated by sunken logs, tree trunks, or similar debris. An experienced operator can remove boulders too large to pass through the dipper, or he can pick up sunken logs and either cast them to one side or load them on floating barges.

While the dipper dredge is peculiarly fitted to recover material from deposits offering too many difficulties for other types of dredges, it must not be assumed that the dipper dredge cannot compete also in easy digging.

Like its land counterpart, this type of dredge can be converted to a floating dragline or clamshell dredge by changing buckets, boom, and possibly boom angle.

Usually dipper dredges are so constructed that they are capable of weathering fairly heavy seas and may be classed as more seaworthy than ladder dredges, although this depends upon the individual design.

Like other types of dredges, they must be built at the excavation site or at some shipyard from which they can be floated to their destination. Dipper dredges are more amenable to standardization in construction, or perhaps it would be more accurate to say that the component parts of a dipper dredge, and the whole assembly within certain limits, are susceptible to standardization. Just as the size of the bucket or dipper and the length of boom or dipper stick can be varied within the overturning limits of the chassis of the dragline, crane, or shovel, so can the same changes be made on a dipper dredge within the buoyancy range of its hull.

Structural Limitations

The depth to which a dipper dredge can dig, the height to which it can raise its loaded dipper, and the radius to which it can reach depend entirely upon the lengths of its boom and dipper stick. Variation in specifications based on the type of excavation for which they are constructed classify dipper dredges into two groups - deep-water dredges and ditching dredges. This differentiation parallels the two main classes of power shovels - the excavator and the stripping shovel. Ditching dredges, as their name implies, are used principally for excavating drainage ditches, and in such work they cast the excavated material to the bank on either side of the ditch. Barges rarely are used for conveyance in this work. This necessitates a higher and wider dumping range than is required for deep-water dredges which dump their material to barges. Because of this differentiation, ditching dredges like stripping shovels are fitted with longer booms and dipper sticks than deep-water dredges.

Ordinarily, the sand and gravel producer is not interested in the extra radial reach or dumping height of either ditching dredge or stripping shovel. However, peculiar local conditions may require them on a particular deposit; therefore, to present the selective possibilities available, the same procedure has been followed in tabulating the structural limitations of dipper dredges as was used with power shovels, that is, no differentiation is made between the two general types. Structural dimensions given in table 41 have been compiled from manufacturers' catalogs; in general, maximum lengths of boom, dipper stick, height of dump, and lateral reach represent the ditching type of dredge and the minimum figures represent the deep-water type, with a considerable overlap between the two extremes. On the other hand, maximum digging depth represents deep-water dredges.

The digging depth is of importance to the gravel producer in that if he contemplates the use of a dipper dredge he must provide the proper length of boom and dipper stick to enable the dredge to reach the bottom of his deposit or leave valuable material behind him.

The dumping height is of less importance because he has only to clear the height of the barge when empty. This, of course, varies with the type of barge used. The flush-deck barge usually rides higher when empty than does the hopper type, although this does not necessarily follow. In any case, dumping height required above the surface of the water is usually less than where a dredge is used for ditching and the dug material must be dumped to either bank.

The dumping radius is also of less importance because in ordinary practice the receiving barge is moored alongside the dredge and the radius available with the shorter boom and stick is sufficient to reach the center line of the barge. Dumping or rather digging radius is important when the dredge is excavating material extending a considerable distance above the surface of the water. With a long radius the dredge can be kept farther from the bank and thus be safer in case the bank caves.

The size, shape, draft, and construction of the dredge hull have a direct bearing on the operating range of the dipper dredge. The arrangement and distribution of operating machinery also affect dredge operation. Hulls must be designed and machinery so distributed as to provide the proper buoyancy and as nearly even keel as possible at all times. Hull construction must be such as to provide adequate strength to resist the terrific stresses set up by the digging dipper and the swinging of loaded dipper, stick, and boom from side to side.

Service Equipment

Dipper dredges are not self-propelled and therefore must depend upon towboats or tugs for movement from one location to another. Like other types of dredges, however, they can be advanced while digging by means of winches through cables and anchors. They can also be swung or "walked" along on their spuds.

To hold the dredge stationary and to prevent careening from the thrust of the dipper, this type of dredge is usually constructed with 2 forward and 1 stern vertical spud. Ditching dredges usually have the forward spuds hinged at the top so the bases can be swung outward and set on the bank at either side. In some dredges anchors and cables only may be used, but such an arrangement without spuds is not customary.

The machinery for generating power to drive the excavating engines, power winches, and usual complement of auxiliary machines is mounted on the dredge hull. Usually quarters for the operating crew are also a part of the structure.

Dipper dredges are usually powered by steam boilers and engines. Smaller sizes may be driven through clutches by gasoline or Diesel engines, and the larger units may use the Diesel engine as the prime mover to drive electric motors.

Because of the diversity of design, there is no exact relation between the horsepower of the power plant and the size of the dipper. Fifty horsepower per cubic yard of dipper capacity may be taken as an approximate indicator of the steam power required. Other types of power will usually exceed these figures in rating, but the plant installed should be designed to fit the needs of the dredge and local conditions.

Capacity

All factors that affect the capacity of a power shovel are present to increase or reduce dipper-dredge capacity. In addition, there are others peculiar to submarine excavation which tend to facilitate or reduce the rate of digging.

The dumping height of a dipper dredge used in the production of sand and gravel usually needs be sufficient only to clear the side of an empty cargo barge. Since these are built as low as possible, the dumping height necessary above water level is usually less than that required of a shovel above its operating base. This reduces hoisting and therefore cycle

time. On the other hand, the dredge reaches much greater depths below water line than does the shovel, which increases its hoisting and cycle time. In addition, the up or down movement of the dipper under water is slower than in air because of the higher resistance of the denser medium. The swing motion (empty return) is slowed up for the same reason, although to a less extent, since the boom is seldom started to swing (loaded) until the dipper is clear of the water. The longer dipper stick and boom also tend to increase cycle time. To overcome this, more power is applied, but this requires heavier construction, reducing the rate of acceleration and deceleration.

Due to the buoyant effect of water, less effort is required to move submerged material than the same material in air. A boulder of exactly 1 cubic foot and weighing 150 pounds in air will require a force of 150 foot-pounds to raise it 1 foot in air. The same boulder submerged in water will weigh 150 - 62.5, or 87.5 pounds, and hence will require only 87.5 foot-pounds of force to raise it 1 foot if water resistance is neglected. This buoyancy is of advantage to the dredge. With a dredge and shovel of equal power excavating identical material, the effect is as if the dredge were digging a lighter material.

The character of the material dug will affect capacity as it does with the shovel. Sticky clay will cause suction as it is torn loose by the dipper. Cemented gravel will be just as hard to dislodge under water as in air. Loose boulders, however, because of their apparently lighter weight, will be easier to move. Sunken logs and tree trunks, for the same reason, can be handled more easily. As an example, a dredge can lift and set aside under water a water-logged tree trunk of greater weight than it could lift out of the water. In this way, such a log could be raised to the surface where lines could be fastened to it, and it could then be towed away by the tug.

The experience and ability of the dredge operator has an even greater effect on capacity than that of the shovel operator. The dredge runner must set his dipper into the deposit blindly as he cannot see the bottom. For the same reason he must clean the bottom by feeling rather than sight. Skill and experience are especially essential in hard digging where the cause of stresses cannot be seen.

The theoretical capacity of a dipper dredge will depend upon the size of the bucket, the digging depth below surface, the speed of hoisting and swinging, the arc of swing, and the height of lift above water line. Since any or all of these items may vary with each dredge unit, theoretical capacities cannot be computed without knowledge of all local conditions.

The working capacities of dipper dredges will necessarily be less than the theoretical ones because of the action of delay factors already discussed.

Table 41 has been compiled from a number of sources as a guide to approximate working capacities. In computing capacities, consideration has been given to the fact that the capacity of a given dredge will vary with the lengths of boom and dipper stick, as well as changes in the depth from which it is digging. The columns showing theoretical capacity are calculated from rope and revolving speeds and assume that a full bucket is handled each cycle. The spread between minimum and maximum is accounted for by the range in lengths of boom and dipper stick and the corresponding digging depths and dumping heights.

Working capacities as estimated make allowance for the customary delays to operation and for partly filled buckets. To arrive at these figures, the lower of the theoretical capacities has been reduced 50 percent and a cubic yard assumed as weighing 2,900 pounds, thus giving an estimated minimum working capacity. The maximum working capacity is computed by reducing the larger of the theoretical figures 50 percent and assuming that a cubic yard weighs 3,240 pounds.

These figures are estimates only, and it is easily conceivable that under the most favorable conditions the maximum capacities may be greatly increased. They may even be doubled for short periods. However, it is felt that the figures given will represent the probable working range day in and day out, including delays of all kinds.

TABLE 41.- Dipper-dredge working ranges and estimated capacities

Dipper capacity cubic yards	Boom length, feet		Dipper stick length, feet		Digging depth below surface, feet		Dumping height above surface, feet		Dumping radius, feet		Capacity per hour			
											Maximum theoretical, cubic yards		Working, tons	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1/2	20	30	16	22	8	12	4	10	15	30	30	70	22	57
3/4	25	35	19	25	10	14	6	12	20	35	35	90	25	73
1	35	60	25	40	13	20.5	9	27	30	60	40	110	29	89
1 1/4	40	60	28	40	14.5	20.5	12	27	35	60	45	140	33	113
1 1/2	40	65	28	43	14	25	11	29	35	65	50	150	36	122
1 3/4	40	75	28	49	14	24.5	11	35	35	75	45	175	33	142
2	40	90	28	58	13	28	10	42	35	90	50	200	36	162
2 1/2	40	90	28	58	13	28	10	42	35	90	65	240	47	194
3	50	100	40	64	20	32	12	48	55	100	90	280	65	227
3 1/2	60	100	40	64	20	32.5	21	48	55	100	120	340	87	275
4	55	85	....	60	28.5	37	25	39	75	94	150	250	109	200
5	55	95	62	65	31.5	40	14	43.5	50	104	120	300	87	243
10	60	....	64	....	....	40	14	18	52	68	360	450	261	365

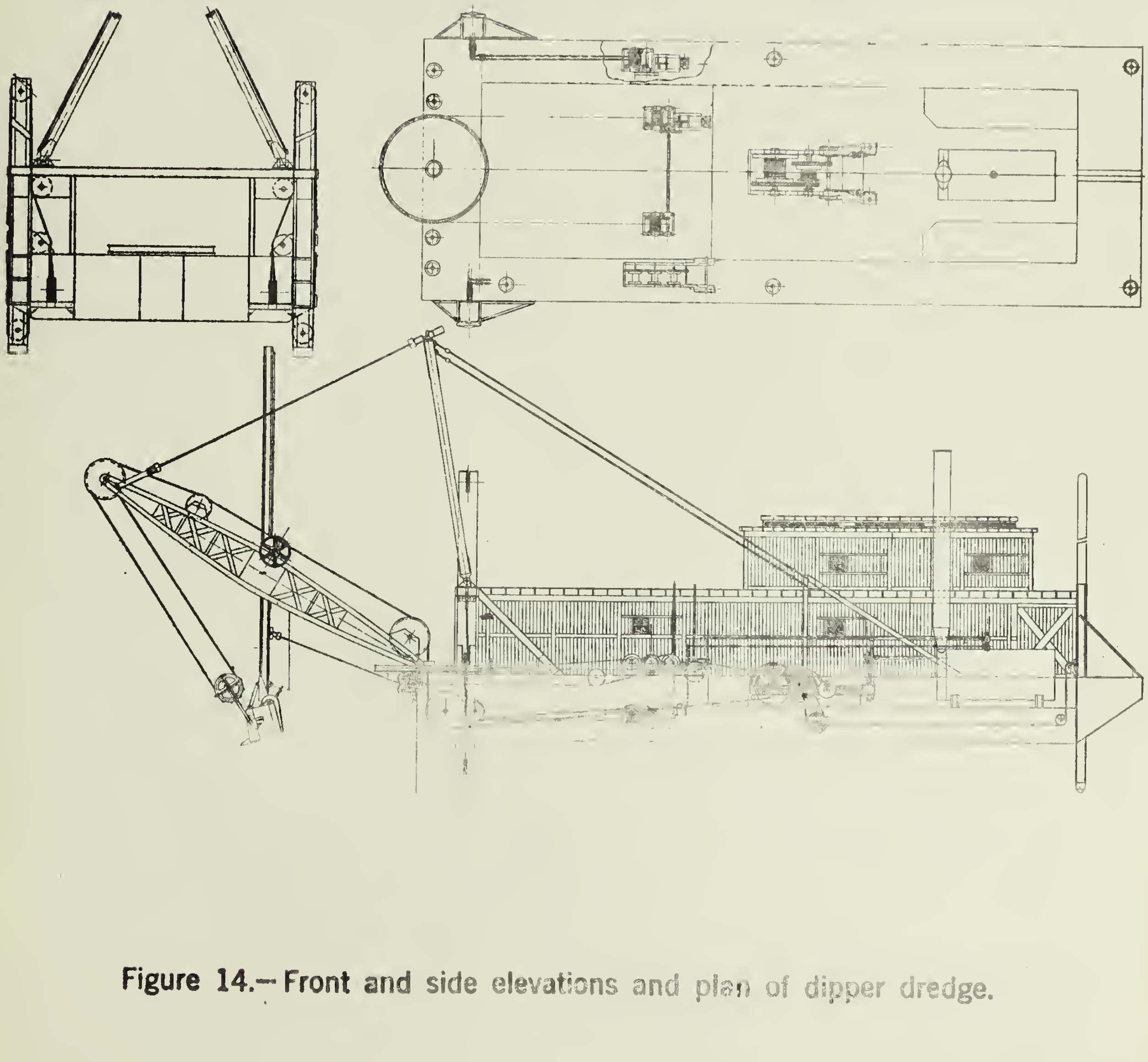

Figure 14.—Front and side elevations and plan of dipper dredge.

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INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SAFETY POSTERS AT THE CALUMET & HECLA MINES[1]

By F. S. Crawford[2]

It has been said that safety promotion passes through four stages--the band-playing, the machine-guarding, the protective equipment, and finally the educational stage; the last is the most important in the development of the safety program.

It has been estimated that only 15 percent of accidents can be prevented by machine guarding and protective equipment; the other 85 percent must be stopped by the safety efforts of the individual workers and their supervisory officials, and one of the fundamentals of safety work is the education of workers to develop safety consciousness or safety mindedness.

One way of educating men to think about safety is by the use of posters. Safety engineers at the Calumet & Hecla mines in Michigan have been conducting a safety contest among the men by the use of posters of an unusual type in addition to those usually employed to illustrate bad practices and to display the number of days without a lost-time accident.

The first requisite for the success of the safety poster is a good artist or draftsman; in the poster contest instituted at the Calumet & Hecla mines two sheets were prepared illustrating various conditions in the slope workings, including a large number of unsafe practices. The object of the contest was to get the men to think about safety through criticism of the unsafe conditions displayed on the posters. The following notice accompanied the posters:

PICTURE PRIZE CONTEST

The contest consists of finding the poor practices shown in the two pictures. Try to find all the poor practices you can--make your answers short. There may be several things wrong in one place. Each man in the pictures is named so that you may be able to tell where the poor practice is.

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6827."

2/ Associate mining engineer, U. S. Bureau of Mines Safety Station, Duluth, Minn.

An easy way to cover the picture is to start with one man--say it is sheet no. 1--then start with Joe--look over this place--note the poor practices. Then take Bill--note all poor practices, etc., until the picture is covered--then look over the other picture in the same manner.

A sample sheet follows:

No. 1 sheet. Henry Jackson. No. 4 Calumet

1. Joe--Drilling near missed hole.

2. Joe ______.

3. Bill ______.

No. 2 sheet.

1. Henry _____.

2. Pat _____.

(Fold your paper and place in your check box.)
SAFETY DEPT.

The contest was initiated by posting this general notice with sheets 1 and 2 (see figs. 1 and 2) in the various change houses, locally termed "drys." The men gathered about the bulletin boards to discuss the posters but did nothing about them until a man from the safety department showed them how to proceed. It was decided, therefore, to hold a contest in only one "dry" at a time and to have a safety man present each day when the men came off the shift.

The value of the contest in developing safety consciousness is indicated by the reaction of the men; those who could not write English but could write the language of their fatherland took notes and had their children write the papers for the contest; those who could not write took their children to the "dry", pointed out the unsafe practices, and had them write the criticisms.

After the contest had been in progress for some time, the safety engineers felt that it would be better to include a large number of safe practices with the unsafe ones in order that the minds of the men would not be dwelling upon unsafe practices alone; this is in accord with psychology which stresses the point that to correct an unsafe practice attention should be focused on the proper or standard method of procedure. It is also in line with the belief that too many "don'ts" are not so effective without corresponding "do's" to indicate the correct methods.

These posters have been useful also in pointing out the hazards to new employees and have been particularly valuable in showing new hoisting engineers underground conditions.

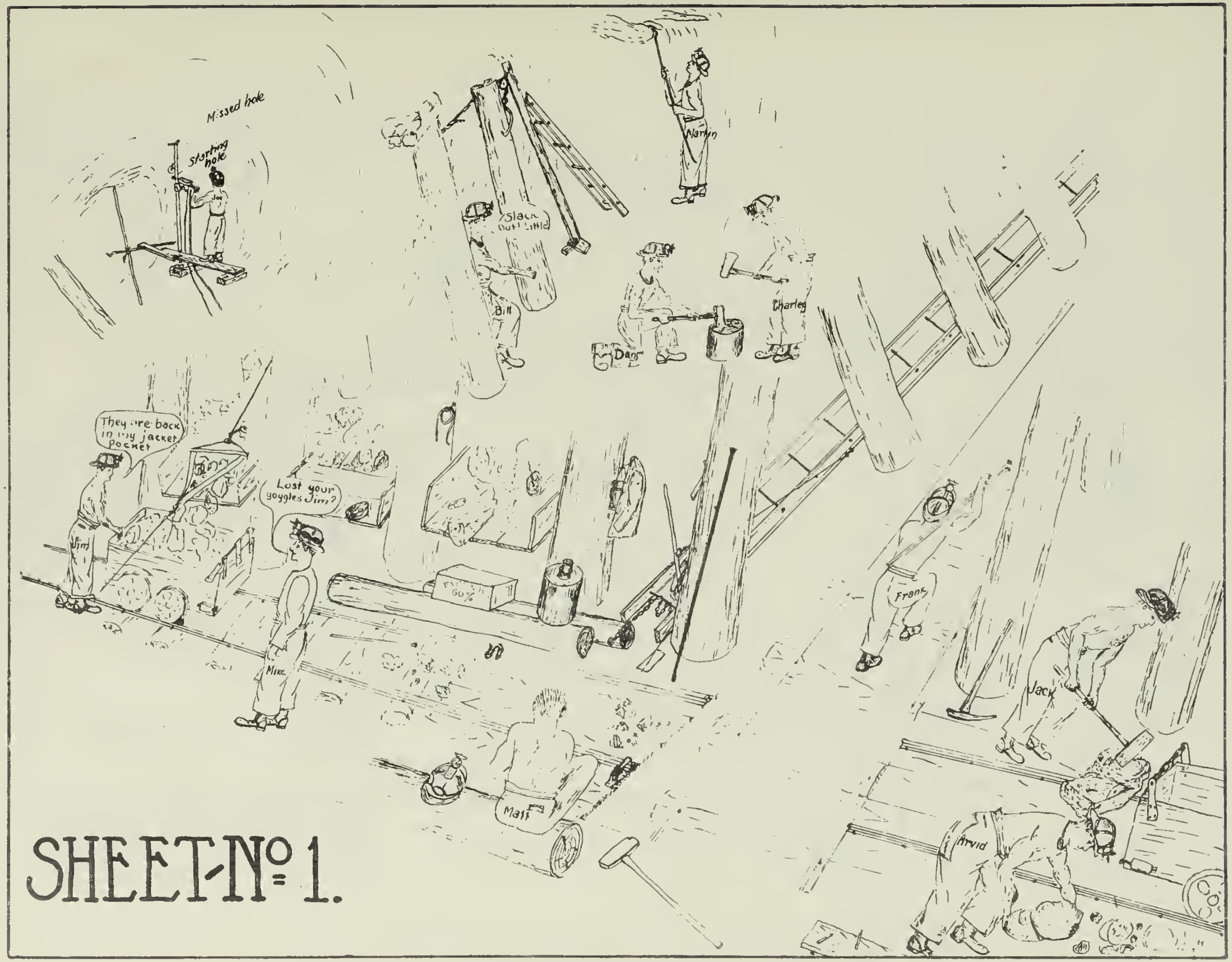

Figure 1.—Poster 1 illustrating poor practices for prize contest, Calumet & Hecla mines.

Figure 2.—Poster 2 illustrating poor practices for prize contest, Calumet & Hecla mines.

It was found essential to the success of the contest for one of the safety engineers to be present to induce all of the men to compete. The less-educated men usually thought they had no chance but entered the contest with interest when told that they could bring their children to do the writing while they dictated the answers or criticisms. This solved a baffling problem, as the object of the contest was to get all of the men to thinking of safety.

PRIZES

Two prizes were offered at each shaft for the best set of criticisms; the first prize was a pair of high-top mining shoes and the second prize a high-grade, up-to-date, hard or safety hat.

The men responded so well that a number of the papers called attention to unsafe practices unintentionally illustrated in the posters. The criticisms were brief and pointed, as is indicated by the following summary of the contest papers.

SHEET 1

JOE:

1. Drilling near missed hole.
2. Starting hole without goggles.
3. Poor stage plank; has a bar and drill and is tied with rope--should be tied with chain.
4. Using a pinch bar for stage support.
5. No collar under arm or machine post.
6. Should blast missed hole before drilling.
7. Should pass hose over stage plank, not under.
8. Should not use bar to build stage.
9. Staging pipe ready to fall.
10. Poor knot on staging.
11. Has no jack bar.

BILL:

1. Standing under log while "slacking out."
2. Working under man barring "loose."
3. Rope partly broken.
4. Ladder should not be left against heaving pole.
5. Should use a chain and not tongs.
6. Using only single rope.
7. Ladder has broken stave.
8. Ladder with iron staves should have tie bolt on each end to keep it from spreading apart.
9. Pole is poorly wedged in the bottom.
10. Loose rock overhead.

MARTIN:

1. Standing under "loose" while barring.
2. Too short a hold on bar.
3. Barring "loose" while men are working below.
4. Hands too close to heel of bar.
5. Thumb up along bar.
6. Does not warn others to stand clear.

DAN:
1. Should be wearing goggles.
2. Using ax for a wedge.
3. Has slivers on ax handles.
4. Should not strike toward his pal.
5. Kneeling in front of his partner's ax.

CHARLEY:
1. Should be wearing goggles.
2. Dan and Charley should use wedges for splitting.
3. Dan and Charley working under man barring "loose."
4. Dan and Charley striking on ax with another ax.
5. Should report poor skip rope to boss.
6. Dumper should be opposite shaft.

FRANK:
1. Should take ladder road instead of shaft.
2. No goggles.
3. May have flint in lamp lighter; wearing a shirt provides some protection. Mike is the only man wearing a shirt.
4. Climbing through shaft with drills.

JACK:
1. Sledging rock without goggles on.
2. Sledge hammer cracked.
3. Striking rock on rail.
4. Breaking rock near partner without warning him.
5. Pick handle loose and split; pick dull.
6. Pick should go to smith shop; broken head.
7. No dumping irons on rails. Holding car from going into skip without irons; may come back and break legs.
8. Slivers on jackhammer handle.
9. Should not use sledge hammer--should use pick.

ARVID:
1. Lifting cracked rock--might break and fall on foot.
2. Should wear goggles while partner is sledging.
3. Should pick up one rock at a time.
4. Should turn down two spikes in the plank on side.
5. Should not have back to the shaft--should be facing other way.
6. Should bend nails over on plank.
7. Should not lift cracked rock.
8. Pick leaning against log; poor handle and head on it.
9. Lifting in wrong position.
10. No bumpers on rails by shaft.
11. Car off track.
12. Strands on cable in back of scraper.
13. Sliver on timber close to lever.
14. No stoppers on rails.

MATT:
1. Sledge head cracked.
2. Not wearing hard hat.
3. Sitting too near shaft; rock might come down and strike him.
4. Drill leaning against timber by shaft.
5. Chain on rung of ladder road.
6. Log obstructing ladder road.

7. Pail and coat hanging in ladder road.
8. Rocks lying in middle of plat at shaft.
9. Rocks not cleaned from track.
10. Mill left open--chute stopper not in.
11. Box of powder under chute.
12. Fuse and cap hanging on timber.
13. Bell lever should be tied up.
14. No dumping iron on foot side rail by shaft.
15. Dirty track.
16. Drill lying on track.
17. Lever not hung.
18. Pick handle split and loose; one end broken.
19. Water can in poor place.
20. Hammer has a poor face.
21. Spikes sticking up in plank and timbers.
22. Hoop iron used for lever hinges instead of a chain.
23. Bell branch-line connection weak.
24. Should not have strap iron for bell lever hanger.
25. Timber lying too close to shaft.
26. Bell lever without any slide on it.
27. No bumper on foot side rail by shaft.
28. Log too near shaft.
29. No dumping irons on north side of shaft and only one on south side.
30. First chute not blocked.
31. Tools should be laid down, not lying against timber.
32. Shiner is off.
33. Water can has grip in poor place.
34. Rock jumped over crosspiece in chute no. 2--ready to fall.

MIKE:

1. Rock lying on edge of chute outside stopper.
2. Standing in front of mill while men are working overhead.
3. Drill lying in center of track.
4. Car should be blocked with a piece of wood, not with a rock.
5. Should not stand in front of chute; loose rock in front of chute should be taken away.
6. Chute should be blocked up; dirt may roll down.
7. Water can should not be on top of logs.
8. Drill should be taken away from timber so it won't fall in shaft.
9. Track should be cleaned up.
10. Loose wire rope on scraper may cut finger on hand.
11. Sledge is poor--should go to smith shop.
12. Has no goggles around his neck.
13. Should remove spike from chute timber.
14. Should remove cap and fuse hanging on log over chute.
15. Timber out past the end of ladder.
16. Chain thrown over ladder stave.
17. No stopper on gate in chute opposite Mike.
18. Rocks coming down open chute may cause an explosion.

19. Foot in way of skip.
20. Lever should be cleaned.
21. Drills should be put in a rack.
22. Bumper on rail by shaft; north side, foot rail.
23. South side, hanging side rail.
24. South side, foot rail.
25. Primer on timber near powder.
26. Should have clear level.

JIM:
1. Should wear goggles on hat or neck.
2. Hand inside car while scraper is working.
3. Standing too near mill while scraper is working.
4. Scraper rope frayed--should be trimmed or tied.
5. Poor block under car wheel.
6. Arm bleeding, should be taken care of.
7. Standing too close to car.
8. Should tie ends of all cables.
9. Should use wedge, not rock, to block car.
10. Should not have a knot with long tail--wire rope, use a hook.
11. Bell line should be hung up when not in use.
12. Pull rope should be spliced.
13. Long tail on scraper rope.
14. "Powder" under chute.
15. Rock under wheel instead of wooden block.

SHEET 2

BOSS:
1. Should be carrying his first-aid kit.
2. Should not tell Paul to use rag to bandage cut.
3. Should insist on "loose" being propped or blasted at once.
4. Has no goggles.
5. Giving poor advise.
6. Should consider small cuts serious, as well as big ones.
7. Should make record of accident.

PAUL:
1. No goggles.
2. Evidently no first-aid box on level.
3. Wears poor shoes.
4. Should not put rag on scratch.

TOM:
1. Standing in front of block while hoisting.
2. Keeping hand on rope while hoisting.
3. Should use a chain, not tongs, in hoisting log.
4. Should not stand in front of tongs.
5. Wears poor shoes.
6. No guard on trigger.
7. Standing inside rope circle.
8. Hoisting log with broken rope.
9. Should wave a light, not call for signals.

MAC:
1. Hand too near saw while cutting piece.
2. Has no goggles.
3. Should not work below scraper pole.

SOL:
1. Has no goggles.
2. Sol and Mac should not cut timber where scraper is running.
3. Has his hand on rope.
4. In angle of blocks.

GEORGE:
1. Needs new hat.
2. Stands too close to car.
3. Should keep hands below car.
4. Broken wire on skip rope.

TIM:
1. Safety clutch not released on car while dumping.
2. Hand on top of rear door while dumping.
3. No goggles around his neck.
4. Stands too close to car while dumping it.
5. Wearing a shirt gives some protection. Only two bosses are wearing shirts.
6. Dumping-car safety clutch out of commission.

CHARLEY:
1. Hand inside car while dumping.
2. Should not be on bridge.
3. Strip rope frayed.
4. Bell should be locked while dumping.
5. Hand on bar of car.
6. Should not be at back of shaft.
7. Safety catch tied down; car might come back and break someone's legs.

ISADORE:
1. Should wear goggles while striking pipe.
2. Should not use hammer on pipe.
3. Should carry wrenches if he intends to fix pipe.
4. Pipe line should be lower.

MATT:
1. Should prop or blast loose rock.
2. Should blast heavy piece of ground before he does any more work.

BOSS JIM:
1. Gives Matt wrong orders.
2. Boss and Matt use poor judgment.
3. Should not permit man to work under loose ground during shift.
4. Should order Matt to bar "loose"; should prop or blast "loose" at once.

HENRY:
1. Hat should be on his head.
2. Should be wearing goggles.
3. Striking with an ax.
4. Rail-cutter head broken.
5. Should not face his partner while striking.

6. Striking on a poor chisel.
7. In front of partner's ax.
8. Shiner off.

PAT:
1. Should be wearing goggles.
2. Rail-cutter head chipped or cracked.
3. Ax is a poor tool for striking cutter--use hammer.
4. Using wood to cut rope on.
5. Loose chain on pole.
6. Should not stay in front of a man striking.

OSCAR:
1. Feet too near shaft--might slip.
2. Hands outside car bar while pushing.
3. Using drill for car-door bar.
4. No goggles around his neck.
5. Should be on the side of car, not in front of car so close to shaft.
6. Poor shoes.

MIKE:
1. Walking backward pulling car.
2. Pulling car past open mill.
3. No goggles around his neck.
4. Should not go below chute while timber is hoisted.
5. Hand on car while it is being filled.
6. Scraper engine has no guard in front of it.

JAKE:
1. Chopping toward knee.
2. Holding piece wrong--thumb in danger.
3. Working too near shaft.
4. No goggles.
5. Making wedges.
6. Slivers on ax handles.
7. Chopping in front of chute where scraper is going.

STEVE:
1. Under timber being hoisted.
2. No stopper in chute.
3. Saw not in safe place.
4. Drill not in safe place.
5. Should not be in chute while timber is hoisted.
6. Wears poor shoes and hat.
7. Leaning saw and drill against log with loose rock behind.

ED:
1. Working under cap piece covered with loose rocks.
2. Working in front of open mill--full of loose rocks.
3. Shovel handle cracked.
4. Should clean rocks off cap piece.
5. Should take crosscut saw and drill from timber.
6. Should throw down rocks from behind timber.
7. Saw and drill in poor place.
8. Tugger engine in poor place.
9. Should roll down rock standing against timber.
10. Should roll rocks ready to come down from stopes.

11. Shovel has sharp points on blade.
12. Shovel leaning on log; loose rock behind log.
13. No guard on crosscut.
14. Didn't take loose rocks off wall plate.
15. Saw should have guard on, with teeth facing down, or should be put in safe place.
16. Rocks hanging in mill should be rolled down to level.
17. Loose rocks on wall plate and rock leaning on leg.

BULLETIN BOARDS

Another feature of the safety-poster work at the Calumet & Hecla mines is the plan for showing the cumulative no-lost-time accident record on the bulletin board. The bulletin boards are located inside each change house and consist of three frames. National Safety Council and Elliott Service posters occupy the two outside frames, while the middle one contains a sketch made locally showing an unsafe practice resulting disastrously, with a warning attached. At the top of the poster is a large figure showing the number of days the shaft has run without an accident. The posters are made up in sets up to 200 days; at first the sets from 1 to 10 days are used more frequently. When a shaft has a lost-time accident it has to start again and is given a different series of posters which have not been used before at that shaft. The posters are changed twice a week; if no accidents have occurred the figure may jump from 10 to 14 days when the posters are changed. Thus, one set of posters may be used again and again at one shaft if the record is broken by an accident and it becomes necessary to repeat.

CONCLUSION

The educational phase of safety is constantly stressed by the Bureau of Mines, but the Bureau does not minimize the value of guarding machinery and the use of protective clothing and equipment. The so-called band-playing stage also occasionally has value in stirring up enthusiasm. For steady year-round safety work, however, education of each individual workman ultimately gives the best results in reduction of accidents, and the safety posters shown in this paper offer a good method of approach, although it is realized that not all mining companies have available an artist of the type available to the Calumet & Hecla Co. for this very excellent educational safety work.

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February 1935

Department of the Interior

United States Bureau of Mines
John W. Finch, Director

INFORMATION CIRCULAR

REVIEW OF COAL-MINE FATALITIES IN INDIANA DURING THE LAST 3 MONTHS OF 1932 AND THE CALENDER YEAR 1933

BY

C. A. Herbert

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INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

REVIEW OF COAL-MINE FATALITIES IN INDIANA FOR THE LAST 3 MONTHS OF 1932 and THE CALENDAR YEAR 1933[1]

By C. A. Herbert[2]

Information Circular 6746 reviewed the fatalities in Indiana coal mines for the fiscal year October 1, 1931 to September 30, 1932. Since then Indiana has changed its fiscal year to the period July 1 to June 30, but as most statistical data on accidents are arranged according to calendar years, the data in this paper are for the last 3 months of 1932 and the calendar year 1933, rather than for the new Indiana fiscal year.

Tables 1 and 2 list the fatalities in Indiana coal mines[3] by cause and occupation for the last 3 months of 1932 and for the calendar year 1933. The fatalities for the small wagon mines employing fewer than 10 men are separated from those employing 10 or more men to call attention to the extremely high fatality rate in small mines, largely because the State mining law does not apply to them nor do they come under the jurisdiction of the Indiana mine inspectors; as a result health and safety conditions are extremely bad.

During the last 3 months of 1932, 5 (approximately 42 percent of the total) fatalities occurred in the small mines, while for the calendar year 1933, 12 (approximately 32 percent) of the fatalities occurred in them.

The Indiana Division of Mines and Mining estimates that these small mines have an annual production of approximately 325,000 tons, or about 4.5 percent of the total coal-mine production of the State. In other words, for these small mines the fatality rate per tons mined during 1933 was about 10 times as great as for the mines employing 10 or more men.

Another lamentable feature in connection with the fatalities in small mines is that very few carry any compensation insurance and the owners are not worth enough financially for dependents of victims to collect anything under the common law; as a result, the dependents of those killed usually are left penniless and subjects of public charity.

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6828."
2/ Supervising engineer, U. S. Bureau of Mines, Vincennes, Ind.
3/ Strip mines are not included.

TABLE 1. - Fatalities in Indiana coal mines for October, November, and December 1932 and the calendar year 1933, by causes

Causes	Fatalities for 1932 1/ in mines employing		Total	Fatalities for 1933 2/ in mines employing		Total
	10 or more men	Fewer than 10 men		10 or more men	Fewer than 10 men	
Underground						
Falls of roof	4	4	8	10	5	15
Falls of coal	-	-	-	1	-	1
Caught between car and rib	1	-	1	1	-	1
Run over by cars	-	-	-	3	-	3
Explosions (windy shots)	-	-	-	5	-	5
Ignition of gas	-	-	-	1	-	1
Caught between car and face	-	-	-	1	-	1
Electricity	-	-	-	1	-	1
Suffocation other than explosion	-	-	-	-	2	2
Falling persons	-	-	-	1	-	1
Explosives	-	-	-	-	3	3
Shaft	-	-	-	-	-	-
Cage	-	1	1	-	1	1
Falling down shaft	-	-	-	1	-	1
Material falling down	-	-	-	1	-	1
Surface						
Electricity	1	-	1	-	-	-
Lifting	1	-	1	-	-	-
Machinery	-	-	-	-	1	1
Total	7	5	12	26	12	38

1/ For October, November, and December 1932.
2/ For the calendar year 1933.

TABLE 2. - Fatalities in Indiana coal mines for October, November, and December 1932 and the calendar year 1933, by occupation

Occupation	Fatalities for 1932[1/] in mines employing		Total	Fatalities for 1933[2/] in mines employing		Total
	10 or more men	Fewer than 10 men		10 or more men	Fewer than 10 men	
Miner	1	4	5	7	7	14
Loading-machine operator and helper	1	-	1	1	-	1
Mining-machine runner and helper	1	-	1	4	-	4
Tracklayer	1	-	1	1	-	1
Underground laborer	1	-	1	-	-	-
Trip rider	-	-	-	3	-	3
Driver	-	-	-	3	-	3
Shot firer	-	-	-	3	-	3
Motorman	-	-	-	1	-	1
Night boss	-	-	-	2	-	2
Face boss	-	-	-	1	-	1
Owner of small mine	-	1	1	-	5	5
Top labor	2	-	2	-	-	-
Total	7	5	12	26	12	38

1/ For October, November, and December 1932.
2/ For the calendar year 1933.

Through the courtesy of A. G. Wilson, Chief Mine Inspector, the fatal accident reports of the deputy mine inspectors were reviewed, as well as the evidence at the coroners' inquests for the period covered by this circular, and the information is summarized for each fatality.

FATALITY 1

A worker at a clay-products plant was killed by a fall of rock while attempting to mine some coal for his own use along the edge of an abandoned strip pit; evidently he was not an experienced miner, as he had made essentially no attempt to protect himself with timber while gouging out the coal under the side of the pit.

FATALITY 2

A loading-machine operator was hit by a fall of rock and died 3 days later. He and his helper had tested the roof shortly before the accident and found the roof slightly drummy. They tried to pull down the loose rock

with a pick but were unable to do so and thought it would be safe to work under until the place was loaded out. The roof was "sweating" and contained some slips, which probably precipitated the fall.

This is another of many cases where men believed they could judge how long it would be safe to work under loose rock, and their judgment proved to be faulty, with disastrous results.

Whenever roof is found to be loose, it either should be taken down or timbered securely before any persons are allowed to work under it.

FATALITY 3

A miner was killed by a fall of rock at the face. Five men were working on a cooperative basis to obtain their winter supply of coal from a small opening in the outcrop of a coal seam. The report does not state whether they were experienced miners, but probably they were not. A fall of slate occurred at the face, striking one of the men and killing him, and while his partners were attempting to remove the piece of rock a second and larger fall injured one of the other men.

Doubtless the danger could have been detected and the fatality avoided if the men had taken time to test the roof properly.

FATALITY 4

A miner employed at a wagon mine was killed by a fall of rock; he was working alone at the time of the accident when a large piece of rock weighing 1 to 2 tons, fell and crushed him.

The report does not state when the roof was tested last or whether the place was well-timbered. Doubtless this fatality could have been averted if the deceased had tested the roof carefully at frequent intervals by the vibration and sounding methods and had taken prompt precautionary action upon finding loose material overhead.

FATALITY 5

A tracklayer was killed by a fall of rock at a room neck; he started to extend track into a room neck when a pit boss, examining the roof, found it to be dangerous, and ordered the tracklayer to stop working until the place was made safe. The tracklayer went up the entry for his truck and with the assistance of the motor boss pushed it to the point where he had been working and where a laborer was getting ready to make the place safe. Upon reaching this point they stopped the truck, and the tracklayer stepped under the loose rock just as it fell.

This accident apparently was due to the carelessness of the tracklayer, as he was fully informed of the dangerous condition of the roof; accidents of this type are by no means uncommon, though they certainly are inexcusable.

FATALITY 6

A laborer on the night shift was killed by being crushed between a car and the rib; he was riding on top of a haulage locomotive and either fell or jumped and was caught between the first car of the trip and the rib. The empty trip was just leaving the shaft bottom and was moving slowly; the motorman did not see the accident but hearing the deceased cry out he immediately stopped the trip and found the deceased standing between the first car and the rib.

The point where the laborer was killed was on a curve where for approximately 6 feet the clearance between the top edge of the car and the rib was only about 6 inches.

This fatality was caused by a combination of two hazardous practices--permitting employees to ride on top of haulage locomotives and failure to provide clearance between cars and rib--which have been responsible for many fatalities.

FATALITY 7

A tipple worker died as a result of rupture caused by lifting a heavy piece of rock; he was working alone after hoisting had stopped removing large pieces of "sulphur" and rock that had been taken from the picking tables during the shift. Lifting one large piece caused a rupture from which he died 2 hours later; this is a type of accident difficult to avoid, yet it would be avoided if employees were instructed as to the maximum weight they should try to lift.

FATALITY 8

A miner in a small wagon mine was killed by a fall of rock; he was working alone turning a room, and had been dead some time when found. The rock that killed him was roughly 4 feet in diameter and 1 foot thick in the thickest place. The report does not state whether the working place had been examined by anyone before the accident, but it probably had not as supervision is usually lacking in these small mines. No doubt the dangerous condition of the roof could have been detected and the accident prevented had proper precautions been taken.

FATALITY 9

A mining-machine helper was killed by a fall of slate. The roof at the face of the entry where the fatality occurred was known to be dangerous because of slips. The face boss stated that he had tested the roof in this place about an hour before the accident occurred and found it to be safe. The report does not indicate whether the machinemen had also tested the roof, but it is presumed they had not, as they had set the machine jack against the loose rock and had just finished "sumping in" when the rock fell. The piece of rock was about 8 feet long, 7 feet wide, and 1 foot thick in the thickest place.

Merely sounding a piece of rock of this size might not give a true indication of its dangerous condition. Roof should be tested by the vibration method—holding the fingers of one hand against the roof and tapping it with a pick or preferably a bar held in the other hand and observing whether the overhead material vibrates or moves slightly when struck, at the same time noting the sound.

FATALITY 10

One of the owners of a small wagon mine was killed by a falling cage. Just as he stepped on the cage to be lowered into the mine, the ring on top of the cage to which the hoisting rope was attached broke and the cage fell to the bottom of the shaft, a distance of 40 feet.

The partner who acted as hoisting engineer stated that he had just turned the steam into the engines and lowered the cage to the ground landing when the accident occurred. The hoisting apparatus had not been examined before the accident, and the hoisting engine had not been operated to make sure the equipment was in good condition. This again is typical of the lack of safety precautionary procedure in the operation of very small mines.

FATALITY 11

A miner was killed by a fall of rock at the face of an entry.

The roof in this mine was generally known to be dangerous and was particularly so at the point where the accident occurred, as a "roll" crossed the entry at this place. The entry face had been shot the night before, and only 1 car of coal had been loaded out at the time of the accident.

Although the timber supply was ample at the crosscut 60 feet back from the face, none had been set within 25 feet of the face.

The deceased's partner claimed that they tested the roof about 20 minutes before the accident and thought it was safe. This is probably another case of knowing that the roof was loose but believing it was possible to judge how long it would be safe to work under it without making it secure; or it is another case of trying to determine the condition of roof by "sounding" rather than by testing by the vibration method. The rock that fell was about 6 feet long, 5 feet wide, and 1 foot thick.

FATALITY 12

A topman was electrocuted by an electric current from a high-tension line.

During construction work a ginpole had been erected under a 3,300-volt high-tension line, the top of the pole being approximately 3 feet beneath the wires. The deceased, who was operating a hand hoist at the bottom of the pole, was electrocuted when the electric current arced from the wires to the steel hoisting rope which ran through a metal pulley near the top of the pole.

FATALITY 13

A trip rider was run over by a moving trip. He was riding on the front end of a locomotive and jumped off and ran ahead of the oncoming loaded trip to open a trapdoor. When he reached the door he stumbled and fell; as he was only about 20 feet from the oncoming trip, the motorman was unable to stop the trip in time to avoid running over him.

A trip consisted of the locomotive, 16 loaded cars, and 1 empty car. The track was downgrade toward the door, which added to the difficulty of stopping the trip.

This is one of many fatalities due to trip riders stumbling and falling in front of moving trips while running ahead to open trapdoors or to throw switches; this is a dangerous practice and one that should not be permitted.

FATALITY 14

A shot firer was killed by an explosion from a blown-out shot caused by overcharged and poorly placed shots of black blasting powder in a mine where the coal is shot from the solid. This fatality and many similar ones that have occurred in Indiana and other coal-mining States as a result of "solid shooting" could have been prevented if the coal had been undercut and shot with permissible explosives. Hundreds, possibly thousands, of lives have been uselessly sacrificed in United States coal mines through the use of black blasting powder.

FATALITY 15

A miner in a small wagon mine was suffocated by explosives fumes. The miner and his son were working at the face of a room 100 feet past the last crosscut. The mine had no fan and had to depend on natural ventilation, which had been insufficient to carry away the fumes from black blasting powder shots fired the previous evening. The father, feeling the effects of the explosives fumes, called for help; by the time help arrived both men were unconscious. The son revived in fresh air, but the father failed to respond to artificial respiration.

Mines employing fewer than 10 men do not come under the State mining law, and the State Inspection Department has no jurisdiction over them; as a result they are usually operated with little regard for the safety of the men employed, and generally the owner or owners are those adversely affected.

FATALITY 16

A miner was killed while retimbering a shaft.

The shaft timbering decayed, and the shaft had caved tight at a certain place. The deceased and another man were standing on the caved material in the shaft while retimbering when the debris suddenly gave way, carrying the two men with it. One escaped injury, but the other was buried and killed.

This fatality could have been prevented by the use of safety belts or a floating scaffold.

FATALITY 17

A miner was killed by a fall of roof near the face of a room in a small, cooperative mine; he had been warned of the dangerous condition of the roof soon after he started to work in the morning and promised either to take down the loose rock or to timber it before loading out the coal. He continued to work under the loose roof, however, doubtless depending upon his judgment as to how long he could work with safety; about 3 hours later the rock fell and killed him. There was plenty of timber in the working place to make it safe.

Often it is not sufficient to tell a workman to make himself safe when he is found working under dangerous conditions; those in charge should practically always stay with him until the place is made safe, or at least until the work of making it safe has been started, and should return at intervals to make sure the work is being done according to instructions.

FATALITIES 18 AND 19

Two shot firers were suffocated by afterdamp from an explosion caused by blown-out shots of black blasting powder.

The coal in this mine is shot from the solid with black blasting powder, and the report indicates that nearly all the shots in this instance were dangerously overcharged. After lighting the shots in the section where the explosion originated the two shot firers retired to a refuge hole, fitted with a strong door, to wait for the shots to explode. The men were found in the refuge hole, suffocated by the afterdamp.

The mine was dry and dusty, yet no protection had been afforded against the propagation of a coal-dust explosion either by rock-dusting or by the application of water.

Undercutting the coal, the use of permissible explosives, rock-dusting at and near the face, and wetting the coal face would have prevented this explosion.

FATALITY 20

A miner was electrocuted by a trolley-wire circuit; he was loading steel rails onto a mine car on the entry. He had lifted one end of the rail onto the car and was lifting the other end from the ground to slide the rail up onto the car when the upper end of the rail came in contact with the trolley wire, electrocuting him. An unsuccessful attempt was made to revive him by administering artificial respiration.

This accident, as well as many others due to loading and unloading supplies underground, could have been prevented if trucks rather than mine cars had been used for transporting material. It is much easier and safer to load and unload a supply truck than a mine car.

FATALITY 21

A miner died 4 days after receiving injuries from falling slate, while riding on a man trip at quitting time.

The deceased and six other men were riding to the shaft bottom at quitting time in a mule-drawn car. A large quantity of slate fell on them from the rib at a high place on the entry. Because of an adverse grade the track had been elevated at the point where the injury occurred, necessitating a considerable amount of roof brushing. No timbering had been done at this point as the roof had arched over and was thought to be safe.

This fatality is chargeable to lack of supervision.

FATALITY 22

A motorman received severe injuries when he either fell or was knocked from his motor. Pneumonia developed, and he died 2 weeks later.

No one witnessed this accident, and the injured man was unable to talk because of his injuries; hence the cause of his fall from the motor and what might have prevented it are unknown.

FATALITIES 23 AND 24

Two night bosses were killed in an explosion caused by blown-out shots of black blasting powder.

Three poorly placed black-blasting-powder shots blew out the stemming on the night before the explosion. At the end of the shift on the night of the explosion the two night bosses reloaded these holes and fired them again; again they blew out, this time causing a violent explosion in which the two bosses were killed.

This explosion was due to recklessness on the part of the victims, who without question knew the danger of firing shots a second time. Better supervision on the part of the company, particularly over the placement of shots, is indicated as being necessary, and again black blasting powder is seen needlessly taking the lives of underground employees.

FATALITY 25

A miner was killed by a fall of slate while running a locomotive; he and another miner were "syndicating" a pair of entries; that is, they were undercutting, shooting, loading, and switching the cars and performing all

the main underground operations of mining necessary to drive the entries. At the time of the injury they were switching a car; the deceased was running the locomotive, and his partner was "lining up" the switches. A large piece of roof fell on the deceased, causing injuries from which he dies about 5 months later.

It appears from the report that the roof at the switch where the injury occurred had not been properly timbered, although the roof was known to contain many slips. This accident is certainly chargeable to poor supervision.

FATALITY 26

A miner was killed by falling face coal.

A miner in a hand-loading mine was undermining standing loosened coal to get a good fall of coal. The face coal gave way suddenly, covering him and inflicting injuries from which he dies 3 weeks later.

This is one of many fatal injuries due to this cause. The practice of first loading the loose coal in front of a shot and then undermining the standing loosened coal to get an easy fall is very dangerous. The face coal should be pulled from the top as the loose coal at the front is loaded.

Lack of supervision and of rules for safe operation are indicated.

FATALITY 27

One of the owners of a small wagon mine was killed by a cage at the bottom of a shaft. There were no witnesses. A few moments before the accident the deceased had pushed a timber truck to within 15 feet of the shaft, the track at this point being downgrade toward the shaft. It is supposed that the deceased failed to block the car, which ran forward toward the cage and struck him just as the cage on which he was standing was hoisted from the bottom; the car which had run onto the cage was caught on the brow of the shaft opening, and the deceased fell into the sump and was killed.

The accident apparently was due to failure of the deceased to block the timber truck properly.

FATALITY 28

A loading-machine operator was killed by a fall of rock; he ordered his helper to knock out some posts that were in the way of the loading machine. About 20 minutes after the posts had been knocked out a large piece of slate which they had been supporting fell and killed the loading-machine operator, seriously injuring a trip rider who was standing near the loading machine at the time of the accident.

Knocking out posts set to support the roof because they are in the way of the loading machine is an extremely dangerous practice, which is followed more or less frequently and as a matter of habit and should be prohibited.

If it is necessary to remove posts, crossbars should be set to replace them, the loose roof should be taken down, or possibly other posts should be set to replace temporarily those which have been removed. This type of accident is far too prevalent where cutting or loading machines are being used in coal mines and is wholly unnecessary if a reasonable amount of time and effort is exerted toward making conditions safe.

FATALITY 29

A driver was run over by his car. No one witnessed this accident, but it is supposed that the deceased was riding on the front end of the loaded car, as is the practice. The track at the point of the accident is down grade; doubtless the driver lost his balance and fell in front of the car while standing on the bumper and leaning forward with one hand on the mule to keep the car from running up on it.

Riding on the front end of cars, although almost universally practiced in Indiana coal mines, is extremely dangerous and has resulted in many fatal and nonfatal injuries.

FATALITY 30

A mining-machine operator was killed by a fall of roof.

The roof in the room where the accident occurred had numerous water slips, and a timberman had been sent into this place to make it secure; he had pulled down a quantity of loose slate and pronounced the room safe about 2 hours before the accident. The drilling crew had left the place only about an hour ahead of the cutting-machine crew and pronounced the roof safe at the time they left.

The helper on the mining machine stated that the roof did not look good and spoke to the runner about it, but the runner said it was all right. The rules at this mine require the mining-machine crews to test the roof before beginning to cut the face, but in this instance they had been delayed because of cable trouble and did not take the time to test the roof properly. While they were oiling the machine after finishing the cut the roof fell and killed the machine runner.

This accident indicates clearly that roof pronounced safe once cannot be expected to remain so indefinitely; if accidents from falls of roof are to be prevented, the roof must be tested at frequent intervals during every working shift.

FATALITY 31

One of the owners of a small wagon mine employing fewer than 10 men received injuries from the sweep of a "gin" hoist, from which he died 10 days later. The deceased was operating the "gin" hoist used for hoisting the cage in the shaft. The counterbalance for the cage broke, causing the sweep to whirl around and strike him, inflicting injuries from which he died.

From the report it appears that the accident was due to lack of proper inspection of the hoisting equipment.

FATALITY 32

A tracklayer was killed by a fall of rock while riding on a haulage locomotive.

The wooden leg supporting one end of a steel crossbar gave way as the locomotive was passing. Two men riding on the front end of the locomotive were uninjured, but the motorman and the tracklayer, who were riding in the cab at the back, were knocked from the locomotive and covered with rock. The motorman escaped serious injury, but the tracklayer was killed instantly.

The failure of the leg was due to decay, and doubtless its condition could have been detected by inspection; the use of treated timber would prevent many accidents of this kind.

FATALITY 33

A trip rider was killed by a fall of rock while standing in the center of a roadway.

The roof in this mine loosens and falls in warm weather and needs close attention. The room boss claimed he had examined the roof about 2 hours before the accident and found it safe.

Doubtless this accident could have been prevented had the entry been supported with crossbars.

FATALITY 34

One of the owners of a small mine was overcome by explosives fumes.

This fatality occurred in a small wagon mine employing fewer than 10 men and hence not under the mining law or the jurisdiction of the State Inspection Department. The mine depended entirely on natural ventilation and had only one shaft.

About 3 hours after quitting time the deceased climbed down buntons to the bottom of the shaft (a distance of 120 feet) to repair a pump; about half an hour later he called for help. As the steam pressure was insufficient to operate the hoisting engine and as it was necessary to send for the hoisting engineer before the cage could be operated, considerable delay ensued in getting the man out of the mine. Fourteen black blasting powder shots had been fired at quitting time, and the deceased was asphyxiated by the fumes from these shots.

This fatality points to the necessity of making all State mining laws applicable to all mines, irrespective of the number of men employed. If this mine had been equipped with a ventilating fan and the mine had been properly ventilated this fatality would not have occurred; and it is entirely probable

that if permissible explosives had been used poisonous gases would not have been present. Moreover, if safety is to be considered no underground coal mine should be operated unless it has more than one opening to the surface.

FATALITY 35

A miner in a small mine employing three men was killed by a fall of rock on the entry while pushing a loaded car.

The roof in this mine is poor, as it has numerous water slips which require careful and close timbering. The timbering, however, had been neglected, as is usual in these small mines, and this neglect is responsible for this fatality.

FATALITY 36

A machine runner was killed by a fall of slate.

The room in which this accident occurred had just passed through a "horseback"; a crack extending from rib to rib had appeared in the roof between thie "horseback" and the face. The loader had just finished loading the coal at the face of the room when the machine crew came in to undercut the place. The loader called the crew's attention to the crack and cautioned them to be careful, whereupon the deceased sounded the top with a pick and declared it safe. Forty minutes later, just as they were finishing the undercut, a large piece of rock fell, killing the machine runner. The rock extended the full width of the room and was about 3 feet thick in the center and 6 feet across.

The roof had not looked safe to the loader, although due to the size of the piece of loose rock it had apparently sounded solid when hit with a pick. Possibly if the machineman had used the vibration method of testing instead of depending upon sound alone he could have detected the dangerous condition of the roof. There was ample timber in the room to make the place safe, and this should have been the first consideration, but frequently machine operators and crews do not care to consume time and effort to set timbers even though their own lives are at stake.

FATALITY 37

A miner in a small mine employing fewer than 10 men was killed by a roof fall. The accident occurred just after work had started in the morning. The miner had pushed an empty car into his room and was digging a ditch to allow the water to drain away from the face. Hearing the roof begin to "work" he started to run back from the face but was caught under the edge of the fall. The piece of slate that fell was about 18 feet long, 16 feet wide, and 1 to 5 feet thick.

The place had not been properly timbered, and as the coal was shot from the solid it is probable that any timber that may have been set was shot out the previous night; shooting off the solid carries with it numerous hazards, among them a considerable difficulty in keeping timbers in place in the face region where the greatest hazards exist.

If the miner had examined the roof carefully when he entered the place, doubtless he would have discovered its dangerous condition and could have taken the necessary precautions to make the place safe.

FATALITY 38

A miner was killed by a fall of top coal while he was helping a tracklayer place a switch at a room neck near the face of the entry. Before starting to work the tracklayer noticed that the overhanging top coal was loose and asked one of the loaders working at the face of the entry to put a prop under it, which he did. Shortly afterward, while a hole was being dug for a tie, the top coal fell, striking one of the miners and inflicting injuries from which he died. The piece of top coal measured about 8 by $4\frac{1}{2}$ feet and was 14 inches thick. Setting the prop under the top coal very probably caused it to break off at the rib; in this case, instead of setting a prop under it the loose top coal should have been taken down, even though it would have delayed the tracklayer in his work. Far too frequently underground workmen neglect their own safety to "save time".

FATALITY 39

A miner fell down the shaft at 6:45 a.m. as the men were being lowered into the mine. The south cage was at the ground landing; the south gate was opened, and the deceased with others walked towards the cage. However, instead of walking onto the cage with the other men he crossed over to the north or empty compartment of the shaft and either stumbled and fell into the open shaft or walked into it with suicidal intent.

The surface landing at this mine is fenced, and the gates are about 10 feet back from the shaft. There are no gates at the top of the shaft to keep persons within the enclosure from falling into the shaft. There should have been gates at the shaft as well as in the enlosure fence.

FATALITY 40

A mining machineman was killed by being crushed between a car and the face. He and his helper were preparing to undercut the face when two cars were accidentally switched into the place. Because of the noise made by a loading machine in a connecting place the deceased did not hear the cars until it was too late to get out of the way, and he was crushed between one of the cars and the face. The switch at the entry had not been lined up with the straight track.

It should be the duty not only of the haulage crews but also of those working at the face to make sure that switches when not in use are "lined up" with the straight track, particularly when the working place is going to the dip. Here is another of numerous fatalities caused indirectly through noise made by machinery of various kinds in use at or near working faces in mines.

FATALITY 41

A miner was killed by a fall of slate; he and his partner were loading a car of coal when a piece of rock, approximately 9 feet long, 7 feet wide, and 5 inches thick, fell and struck him on the head, fracturing his skull.

The timbering in the room was too far back from the face for safety, although the ample supply of posts close at hand could have been used to make the place safe.

The deceased's partner claims they tested the roof a short time before the accident occurred and that the roof sounded solid. This fatality again exemplifies the danger of depending solely on sound when testing roof; unquestionably the vibration method should be used.

FATALITY 42

A farmer was killed by a fall of rock in a small mine, while he and another farmer were getting out their winter supply of coal from a small slope mine or farm. The two men had timbered the place well and had sounded the sandstone top and thought from the sound that it was safe.

While the deceased was mining some coal along the rib, a piece of sand rock about 6 feet long, 3 feet wide, and 18 inches thick fell out between the ribs and the posts, crushing him.

This is another instance in which testing roof by sound alone did not give a true indication of its dangerous character. The vibration method should always be used as it not only gives the sound but also indicates whether the material under test vibrates or moves when struck by the bar in testing.

FATALITY 43

A driver was killed by a fall of rock on the shaft bottom 20 feet from the shaft. He had stopped to fill his carbide lamp when a piece of rock about 5 feet long, 4 feet wide, and 12 inches thick fell on him, inflicting injuries from which he died about 12 hours later.

The deceased had called the mine bosses' attention to the dangerous condition of the roof 2 days before the accident, but nothing had been done to make it secure. This fatality is chargeable to carelessness of the mine management.

FATALITY 44

A face boss was burned so severely by the ignition of a pocket of gas by an open light that he died a month later.

On the night before the accident the fire boss had noticed "drippers" in the roof of the room where the accident occurred but found no gas. He

reported the drippers to the superintendent and suggested that the place be kept under close supervision. The next day (Sunday) the room boss was looking after some emergency timbering nearby and went in to examine the place in which the drippers had been observed. Apparently a fall liberating methane had occurred in the room between the time of the fire boss's visit and that of the room boss. The room boss walked into the room wearing a carbide lamp which ignited the gas, and he received burns from which he died a month later.

At many mines in Indiana the bosses are required to wear electric cap lamps and carry lighted flame safety lamps with them at all times. If such a rule had been in force at this mine, doubtless this fatality would not have occurred. Regardless of this fact the room boss, knowing that roof drippers are often followed by falls and gas, of his own accord should have made an examination for gas in this room before entering with his open light. This is a type of accident which is going to occur with more or less monotonous regularity just as long as open lights are used in coal mines.

FATALITIES 45, 46, AND 47

Three miners working in a small mine died as a result of burns caused by accidental ignition of black blasting powder while charging shot holes; the employees at the mine had attended a union meeting, following which the owner of the mine intended to go below and blast, but knowing his father was not feeling well the 16-year old son of the owner and 5 other men volunteered to do the blasting for him.

While one of the men was making a cartridge of black blasting powder his cap and carbide lamp fell from his head into the explosive, igniting both the cartridge and the explosive in the keg. The 6 men in the room were severely burned, 3 of them so severely that they died.

It is dangerous to use black blasting powder, even when it is handled carefully. The practice of making cartridges of black blasting powder while wearing an open light or in proximity to an open light is extremely hazardous and has resulted in scores of fatalities in coal mines of the United States.

The mine owner either should have done the blasting himself, as was his custom or should have designated a competent man to do it for him instead of allowing 6 inexperienced men to attempt to do the shooting.

FATALITY 48

A trip rider was crushed between a car and the rib.

An empty trip was being pushed around a turn into a pair of side entries to couple to two empty cars that had been left there on a previous trip. The trip rider was riding on the bumper on the outby end of the last car; this car, while being pushed around the turn, jumped the track, catching the trip rider between the corner of the car and the rib.

Riding the front bumper of a pushed trip is a dangerous practice. The trip rider should have ridden inside the car.

FATALITY 49

A mining-machine runner was injured by a fall of rock from which he died about 3 months later.

The coal at this mine is loaded mechanically, and the regular cycle of operation is for the timberman to follow the loading machine and to make the place safe ahead of the undercutting or drilling crews. On this particular day a change in timberman had been made, and the new timberman had failed to make the working place safe ahead of the undercutting crew. The latter was in a hurry and failed to examine the place, evidently depending on the timberman to make the place safe. The instructions to machine crews at this mine are to examine the roof before beginning to undercut, but in this instance the crew failed to do so.

Inasmuch as a new timberman was working on the day of the accident, the boss in charge should have made sure to visit the working places to determine their safety ahead of the machine crew. The machine crew was also remiss in not carrying out instructions to examine the roof before beginning to work. this accident was due to carelessness of both workers and management.

FATALITY 50

A loaded car ran over a driver, who received injuries from which he died the same day.

The deceased was riding on the front end of a two-car trip. As the track was downgrade and no sprags were used, he was doubtless standing with one hand on the mule to keep the cars from hitting it, and the mule stumbled, causing the driver to fall in front of the car.

Riding on the rear end of trips is the practice in many mines; if it had been the practice at this mine this accident would not have occurred.

SUMMARY

Fatalities for the entire 15-month period have been tabulated in table 3 to show occupation, cause of fatality, cause of accident, and how accident could have been prevented. Under the caption "Responsibility for accidents," an attempt has been made to fix the responsibility for each fatality; a summary of the assigned responsibility is included at the bottom of the table.

TABLE 3. - Occupation, cause of fatality, cause of accident, means of prevention, and responsibility for accident
October to December 1932

Case	Occupation	Cause of fatality	Cause of accident	Means of preventing accident	Responsibility for accident
1 1/	Miner (getting out his winter coal)	Fall of rock.	Lack of experience; lack of timbering.	Timbering.	Miner.
2	Loading-machine operator	Do.	Carelessness; faulty judgment of injured; lack of timbering; lack of supervision.	Pulling down loose rock; better supervision.	Miner and company.
3	Miner	Do.	Failure to test roof.	Testing roof; pulling down loose rock or timbering.	Miner.
4 1/	Do.	Do.	Do.	Testing roof; pulling down loose rock or timbering; better supervision.	Miner and company.
5	Tracklayer	Do.	Carelessness.	Education of workman in safety.	Workman.
6	Laborer	Crushed between car and rib.	Lack of clearance; riding on top of locomotive.	Proper clearance; prohibit riding on locomotives.	Company.
7	Top laborer	Lifting heavy rock.	Faulty arrangement in tipple, making it necessary to lift rock.	Lowering rock chute.	Do.
8	Miner	Fall of rock.	Failure to test roof; lack of proper supervision.	Proper testing of roof; proper supervision.	Miner and company
9	Mining machine helper	Do.	Failure to test roof properly.	Greater care on part of workman.	Workman.
10 1/	Owner	Falling cage.	Breaking rope connection to cage.	Daily testing of hoisting apparatus.	Company.
11	Miner	Fall of rock.	Failure to test roof properly and to make place safe.	Either taking down or timbering loose roof; better supervision.	Miner and company.
12	Topman (not company employee)	Electricity.	Setting gin pole too close to high tension wires.	Setting gin pole farther away from wire	Contractor doing construction work.

1/ Mine employing fewer than 10 men.

TABLE - Occupation, cause of fatality, cause of accident, means of prevention, and responsibility for accident--Continued

Calendar year 1933

Case	Occupation	Cause of fatality	Cause of accident	Means of preventing accident	Responsibility for accident
13	Trip rider	Run over by cars.	Jumping off and running ahead of moving trip.	Stopping trip and not permitting trip riders to jump off or on moving trips.	Company.
14	Shot firer	Suffocation.	Blown-out shot of black blasting powder.	Undercutting coal; permissible explosives.	Do.
15 1/	Miner.	Do.	Black blasting powder fumes; lack of ventilation.	Better ventilation.	Do.
16	Do.	Material falling in shaft.	Failure of company to provide proper safeguards.	Providing men with safety belts or floating platform.	Do.
17 1/	Do.	Fall of roof.	Failure to follow instructions of company either to timber or take down loose rock.	Timbering and better supervision.	Employee and company.
18	Shot firer	Suffocation.	Blown-out shot of black blasting powder; dust explosion.	Undercutting coal; permissible explosives.	Company.
19	Do.	Do.	Do.	Do.	Do.
20	Miner	Electric shock.	Lifting steel rail on top of car in proximity to trolley wire.	Using low truck for hauling material; cut off power.	Do.
21	Do.	Fall of slate from rib.	Lack of examination of roof and ribs on roadway.	Better supervision.	Do.
22	Motorman	Falling off moving locomotive.	Unknown.	Unknown.	Unknown.
23	Night boss	Violence from explosion.	Dust explosion due to firing dangerous black blasting powder shots.	Using permissible explosives.	Man and company.
24	Do.	Do.	Do.	Do.	Do.
25	Miner	Fall of rock.	Failure of company to keep roof on entry safe.	Better supervision.	Company.
26	Do.	Fall of face coal.	Undermining standing coal.	Pulling down loose coal on face as coal is loaded out; better supervision.	Miner and company.

1/ Mine employing fewer than 10 men.

TABLE 3. - Occupation, cause of fatality, cause of accident, means of prevention, and responsibility for accident--Continued

Calendar year 1933--Continued

Case	Occupation	Cause of fatality	Cause of accident	Means of preventing accident	Responsibility for accident
27 1/	Owner	Cage.	Improper blocking of car.	Blocking cars at shaft bottom.	Owner.
28	Loading-machine operator.	Fall of rock.	Knocking out props under loose rock.	Making place safe before removing props in the way of loader.	Man and company.
29	Driver	Run over by car.	Riding on front end of car.	Better supervision; riding on back end of car.	Company.
30	Mining-machine runner.	Fall of rock.	Failure to test roof.	Testing roof and setting timber or pulling down loose rock.	Employee.
31 1/	Owner	Hit by gin sweep	Failure to inspect hoisting equipment.	Better supervision; inspection of hoisting equipment.	Owner.
32	Tracklayer	Fall of rock.	Failure by decay of wooden leg supporting crossbar; lack of inspection.	Closer inspection of timbering on roadways; use of treated timber.	Company.
33	Trip rider	Do.	Failure to timber entry properly.	Proper timbering of entry under poor roof.	Do.
34 1/	Owner	Suffocation.	Black blasting powder fumes; lack of ventilation.	Proper ventilation.	Owner.
35 1/	Do.	Fall of rock.	Lack of timbering.	Making entry secure by proper timbering.	Do.
36	Mining-machine runner.	Do.	Failure to test roof properly; faulty judgment.	Proper timbering of room or pulling down loose rock.	Employee.
37 1/	Miner.	Do.	Failure to test roof; lack of timbering; lack of supervision.	Proper timbering; better supervision.	Company
38	Do.	Do.	Failure to pull down loose top coal; faulty judgment.	Pulling down loose top coal.	Miner and tracklayer.
39	Do.	Fell down shaft.	Lack of gates at top of shaft.	Gates at top of shaft.	Company.
40	Machineman	Caught between car and face.	Failure to line switch with straight track.	Rules covering haulage and proper enforcement of them.	Other employee and company.

1/ Mine employing fewer than 10 men.

TABLE 3. - Occupation, cause of fatality, cause of accident, means of prevention, and responsibility for accident--Concluded

Calendar year 1933--Concluded

Case	Occupation	Cause of fatality	Cause of accident	Means of preventing accident	Responsibility for accident
41	Miner	Fall of rock.	Failure to timber place properly; improper testing.	Keeping place properly timbered; frequent testing of roof.	Man and company.
42 1/	Owner.	Do.	Failure to test roof properly.	Using vibration and sounding methods of testing.	Owner.
43	Driver	Do.	Failure by company to make entry safe; dangerous condition was known.	Placing necessary timber.	Company.
44	Face boss	Ignition of gas.	Failure of boss to examine for gas; failure of company to require bosses to carry electric cap lamps and flame safety lamps.	Testing for gas; company requiring bosses to use electric cap lamps and carry flame safety lamps.	Employee and company.
45 1/	Miner	Ignition of black blasting powder.	Wearing open light while handling black blasting powder.	Taking lamp off head and placing at safe distance.	Men and company.
46 1/	Do.	Do.	Do.	Do.	Do.
47 1/	Do.	Do.	Do.	Do.	Do.
48	Trip rider	Crushed between car and rib.	Riding on bumper permitted by company.	Riding inside car.	Company.
49	Machineman	Fall of rock.	Failure of machineman to test roof, depending on others for his own safety; lack of supervision.	Testing roof; better supervision.	Man and company.
50	Driver	Run over by car.	Riding on front end of car; mule stumbled.	Riding on rear bumper, using sprags going downhill	Company.

1/ Mine employing fewer than 10 men.

Responsibility:

Employee or individual killed	8
Employee or individual killed, and company or owner	19
Company or owner	20
Fellow employee and company or owner	1
Unknown	1
Employee killed and fellow employee	1
	50

CONCLUSIONS

With the exception of the one fatality of unknown cause, the evidence indicates that all fatalities might have been prevented if the men, the company, or both had taken the available precautions.

Unquestionably mine accidents, both fatal and nonfatal, can be greatly reduced; there are now too many outstanding examples of what has been accomplished along this line for any other conclusion. Companies have succeeded in reducing accident rates largely by learning from past accidents to eliminate as far as possible the dangerous conditions and practices that have caused these accidents and thus have prevented their recurrence.

This review of fatal accidents in Indiana has been made with the hope that lessons may be drawn from them that will tend to prevent similar accidents in the future.

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DEPARTMENT OF THE INTERIOR

UNITED STATES BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

BITUMINOUS COAL-MINE SAFETY-INSPECTION OUTLINE

BY

G. W. GROVE AND W. J. FENE

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I.C. 6829,
March 1935.

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

BITUMINOUS COAL-MINE SAFETY-INSPECTION OUTLINE[1/]

By G. W. Grove[2/] and W. J. Fene[3/]

An important activity of the Safety Division of the Bureau of Mines, in its efforts to reduce accidents, is the safety inspection of mines. Inspections are made at the request of the operators and are not connected with the inspections by the various State departments of mines. The operating management is furnished with a confidential report of the results of the Bureau's inspections, with recommendations for elimination of the hazards found. These mine-safety inspections include a study of mining practices, conditions, and equipment and in some cases the sampling and analysis of mine air and coal dust.

The Bureau of Mines has no regulatory powers, therefore the recommendations made in these reports are merely suggestions, and operators are not required to adopt them.

Mine inspections are a check on safety standards, methods, and practices and are essential to any accident-prevention program. A foreman or superintendent may be sincere in his efforts to operate a mine safely and believe that he has done everything possible to attain this end. However, experience has shown that because of his familiarity with the mine and the consequent "nearness" of its various features many unsafe conditions may be, and in most cases are, overlooked; an inspector, particularly an outsider who is trained to look for hazards, can point out the unsafe conditions overlooked by the foreman or superintendent.

Some companies employ safety engineers who make regular inspections of their mines, report substandard conditions and hazards found, and make recommendations for correcting them. Unless these recommendations are carried out the inspections have little value. In making recommendations, due consideration should be given to the feasibility of carrying them out; the management may and very often does consider a recommendation impracticable because of the

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1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6829."

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cost involved in putting it into effect; but in most cases, if the recommendations are made by a competent safety inspector, an actual saving will be effected by the expenditure necessary to correct existing hazards.

A mine inspection, like any other investigation, should be made in accordance with a definite plan or outline; as a result of years of experience in making mine inspections, Bureau of Mines engineers have compiled a standard outline representing the data essential for the preparation of a detailed mine-inspection report. The outline, prepared in convenient booklet form, is comprehensive and covers practically every condition that may be found in and around bituminous-coal mines. It is published here with the hope that it may be found useful to those making mine inspections and preparing reports thereon. In using this outline at a mine for the first time, the inspector should record the information as completely as possible, so that in subsequent inspections of the same mine it will be necessary to note only changes in conditions or practices since the last inspection. The outline is so inclusive that many of the provisions will be found not applicable to any certain mines, and on the other hand there are very few mines or types of mines that the outline would fail to cover with regard to essential safety features. The outline has been in use by Bureau of Mines field safety men for several years, and the following is a relatively recent compilation embodying some features added through suggestions received from the field men of the Bureau's Safety Division.

SAFETY-INSPECTION OUTLINE FOR COAL MINES

1. Engineer making inspection________________________
2. Date of inspection________________________

GENERAL INFORMATION

3. Name of mine________________________
4. Name of operating company________________________
5. Mine location (State, county, town, distance and direction from town, railroad)________________________
6. Name and address of operating officials:
   a. President________________________
   b. Gen. mgr. or gen. supt.________________________
   c. Chief engineer________________________
   d. Superintendent________________________
   e. Safety engineer________________________
   f. Mine foreman________________________
7. Other mines operated by same company________________________
8. To whom should report be sent?________________________
   Address________________________
9. History of mine and district. (Give approximate date mine was opened. Make statement as to explosions, fires, or other disasters occurring in this mine, and fires and explosions occurring in adjoining or adjacent mines working same coal bed.)________________________
10. Type of mine:
    Drift________________________
    Slope____________; pitch____________; length____________
    Shaft____________________; depth____________________
11. Coal bed:
    a. Geological and local designation________________________
       Average thickness________________ Dip________________
       Kind of coal________________ Maximum cover________________
    b. Number of beds worked________________________
    c. Impurities (variability and character)________________________
    d. Analysis of coal________________________
    e. Ratio of volatile to total combustible________________________

12. Number of employees:
    a. Underground____
    b. Surface____
    c. Loaders____
    d. Daymen____
13. Production:
    a. Daily average____
    b. Maximum daily____
    c. For year____
    d. Probable life of mine____

SURFACE PLANT AND EQUIPMENT

14. Tipple or cleaning plant:
    a. Construction____
    b. Fire protection____
    c. Sizes of coal produced____
    d. Type of screens____
    e. Wiring properly installed____
    ____
    f. Dust hazard, precaution taken____
    ____
    g. Frequency and method of cleaning____
    ____
    h. Stairways: Adequate____
    Guarded____
    i. Machinery and belts guarded____
    ____
    j. Safety and method of handling railroad cars____
    ____
    ____
    k. Any other hazards noted____
    ____
    ____
    ____
15. Refuse disposal:
    a. Dump car____________________ Larry____________________
    Aerial tram____________________ Truck____________________
    b. Distance of waste dump from intake opening____
    c. Hazards in connection with refuse disposal (describe)____
    ____
    ____
    ____
16. Coal-storage bins:
    a. Capacity and distance from mine openings____
    b. Spontaneous fires in storage of coal____
17. Headframe (if shaft mine)____
    a. Is there a railed platform at head sheaves?____
    b. Railed stairway leading thereto?____
    c. How often are sheaves inspected and oiled?____
    d. Is this inspection recorded?____

18. Surface haulage (if drift or slope):
    a. Condition of track ____________ Road bed ____________
    b. Clearance ____________
    c. Are frogs and guard rails blocked? ____________
    d. Slope leading to surface:
        Condition of track ____________
        Type of drags used--derails or safety blocks ____________
        ____
        Clearance ____________
    e. Outside planes or inclines ____________
        Pitch ____________ Length ____________
        Positive stop blocks at top ____________
        Derail near top ____________
        Derail near tipple ____________
        Drags ____________
        Is barney or monitor used? ____________
        Are man-trips operated on surface planes? ____________
        What safety precautions are taken? ____________
        ____

19. Hoisting equipment:
    a. Type ____________ How driven ____________
    b. Overwind device ____________ Speed control ____________
        Other safety features ____________
        ____
    c. Enginehouse:
        Construction ____________
        Fire protection ____________
    d. Are hoisting engines placed so that noise of other machinery will not prevent engineer from hearing signals? ____________
        ____
    e. Are periodic physical examinations given engineer? ____________
    f. Is hoisting equipment inspected? ____________
        How often? ____________ By whom? ____________

20. Cages:
    a. Type ____________
    b. Bonnet:
        Bars or chains across ends ____________
        Lining or rail and toe board on guide sides ____________
        Hand holds ____________
        Bridle chains ____________
    c. Safety catches:
        Frequency of tests ____________
        Is record kept of tests? ____________
    d. How often are cage, guides, and shaft lining inspected? ____________
    e. Is there a positive stop block at surface landing? ____________
    f. Kind of gates provided at surface landing ____________
    g. Is cager in charge while men are riding on cage? ____________
    h. Maximum number of men allowed on cage ____________
    i. Method of signaling ____________
    j. Are movable parts locked while men are riding on cage? ____________

k. Are tools carried on cage with men?________________
l. Speed at which men are hoisted________________
m. Can signals be given from cage?________________

21. Steam plant:
a. Number of boilers__________ Size_________ Type____________
b. Building________________
c. How often are boilers inspected?________________
d. Safety devices________________
e. Number of exits from boiler room________________

22. Electric power plant:
a. Number of generators____________ Type________________
Alternating current or direct current________________
Voltage________ Kilovolt amperes or kilowatt rating____________
Properly grounded________________
b. Safety of installation________________
____
c. Kind of building________________
Fire protection________________
d. Switchboard________________
Adequately guarded________________
Rubber mat on floor________________
e. Fire hazards________________
f. Oil storage________________
g. Cleanliness________________
h. If power purchased, from whom?________________
i. Voltage received at________________
j. Auxiliary power lines________________

23. Surface transformer station:
a. Are transformers well-installed?________________
Type of building________________
b. How guarded or enclosed?________________
c. Is door or gate kept locked?________________
d. Are transformers properly grounded?________________
e. Voltage incoming________________ Outgoing________________
f. Are proper lightning arresters installed?________________

24. Substation:
a. Kind of building________________
Fire protection________________
b. Motor-generator sets________________
Voltage, alternating current__________ Direct current__________
c. Properly grounded________________
d. Switchboard:
Adequately guarded________________
Rubber mat or insulated platform on floor________________
e. Circuit breakers and fuses________________
f. Is door to building kept locked?________________

25. Surface power and trolley lines:
a. Height of trolley wire above rail________________
b. Guarding of wires, method________________
c. Securely supported on insulated hangers________________
d. Alinement________________

26. Shops:
    a. Building____________________
        Fire protection____________________
    b. Wiring____________________
    c. Machine and belt guards____________________
    d. Open repair pit____________________
        Is pit covered when not in use?____________________
    e. Use of goggles__________ Type__________
    f. Condition of hand tools____________________
    g. Cleanliness of building____________________
    h. Safety of electrical equipment____________________
    i. Illumination____________________
    j. How heated____________________

27. Fan and fanhouse:
    a. Type of fan__________ Size__________ Capacity__________
    b. How driven____________________
        Operating exhausting or blowing____________________
    c. Is there reserve power?__________ Auxiliary fan?__________
    d. Location of fan in relation to opening____________________
    e. Can air current be reversed?____________________
        If so, how often tested?____________________
    f. Explosion doors or weak wall____________________
    g. Water gage__________ Kind__________
    h. Signal device to show when fan slows down or stops__________
    i. Are fan and fanhouse casing of incombustible material?__________
    j. How often inspected?__________ By whom?__________
    k. Is fan on independent circuit?____________________
    l. Is fan run continuously?____________________
    m. When stopped are men all out of mine?____________________
    n. How long before men enter is fan started?____________________

28. Explosives storage magazine:
    a. Material of construction____________________
    b. Kind of floor____________________
    c. Capacity__________ Maximum stored__________
    d. Distance from nearest mine entrance____________________
        From nearest building____________________
        From public highway____________________
        From transformer____________________
    e. Barricaded?__________ How?__________
    f. Danger signs properly located____________________
    g. Properly screened ventilators____________________
    h. Illumination of magazine____________________
        Location of switch____________________
    i. Is other material stored in magazine?____________________
    j. Is area around magazine kept free of dry grass and brush?__________
        Cleanliness of magazine____________________
    k. How is excess summer temperature prevented?____________________
    l. How secured against unlawful entry?____________________
    m. Frequency of delivery to____________________

n. Are explosives inspected on arrival?
o. Is fuse tested to determine burning rate?
p. What disposal is made of old explosives and detonators?

29. Distributing magazine:
a. Material of construction
b. Distance from nearest mine opening
From nearest building
c. Is more than 1 day's supply of explosives kept in magazine?

d. Illumination of magazine
Location of switch
e. Tools used for opening boxes
f. Are there separate distributing magazines for explosives and detonators? Distance apart
g. Are other things stored with explosives?
With detonators?
h. Do unauthorized persons enter magazine?
i. Method of distributing explosives
j. How are explosives delivered to magazines?

30. Wash-house:
a. Description
b. Fire hazards
c. Cleanliness
d. Are toilet facilities provided?
e. Illumination
f. How heated

31. Supplyhouse:
a. Construction
b. Fire protection
c. Orderly method of storing
d. Illumination
e. How heated

32. Lamphouse:
a. Construction
b. Equipment
c. Kind of lamps Number
d. Maintenance
e. Where is naphtha stored?
f. Illumination
g. How heated

33. Other buildings: Describe

34. Yards and material storage:
a. Are roads, paths, and walks kept free from obstructions?
b. Are timbers, ties, and rails properly stored and piled?
c. Are scrap iron and old cars properly stored?

35. Surface fire protection:
a. Is any inflammable building within 100 feet of mine opening?
b. Describe fire protection provided

c. Is fire extinguishing equipment tested?____________________
How often?____________________________________
d. Method of storing oil on surface________________________
Describe any hazards______________________________

36. Water supply, sanitation, housing of employees__________________

37. System of checking men into and out of mine: Describe____________

UNDERGROUND MINING METHODS, CONDITIONS, AND EQUIPMENT

38. System of mining (longwall, room-and-pillar, butt entries, panels, long faces, etc.)____________________
a. Is mine laid out with reference to butts and faces?________
b. Number of main entries (two, three, four, etc.)____________
c. Distance between levels or cross entries________________
d. Number of side entries (double, triple, etc.)_____________
e. Entry width____________ Pillar width____________
Brushed____________ Distance between crosscuts__________
f. Rooms: Width____________ Pillar width____________
Length____________ Distance between crosscuts__________
g. Are rooms turned off aircourses?____________________
h. Are rooms of one entry driven into rooms of an adjacent entry?____
i. Are pillars recovered?________Describe method____________
Is a definite pillar line maintained?________ What method is used to maintain pillar line?____________________
j. Is coal cut or sheared?________ Is cutting done in floor or coal?____________Are cuttings left in mine or loaded out?____________Are cuttings loaded out before or after shooting?____________ Depth of cut or shear________
k. Proportion of coal recovered in advance work______________
l. Total recovery, excluding roof coal____________________
Including roof coal______________________________

39. Roof and floor:
a. Immediate roof (kind and quality, thickness of drawslate or roof coal)____________________
b. Main roof (kind, average thickness, maximum cover)____________
c. Frequency of slips, rolls, pots, horsebacks, faults, and clay veins____________________
d. Floor: Kind____________Soft or hard____________
Smooth or rough______________________________

40. Timbering:
   a. Entry timbering:
      Is dangerous or doubtful slate, rock, or coal promptly taken down?______________ Or timbered?______________
      When?______________
      Method of timbering______________
      Are entries adequately timbered?______________
      Are safety posts used?______________
   b. Room timbering:
      Is dangerous or doubtful slate, rock, or coal promptly taken down?______________ Or timbered?______________
      When?______________
      Number of rows of posts______________ Distance between posts______________ Or cross bars______________
      Distance from face______________
   c. System of timbering in pillar work______________
   d. Are prepared cap pieces and wedges provided?______________
      Size______________
   e. If prepared cap pieces are not provided, are those used adequate?______________
   f. Is the coal spragged after undercutting?______________
   g. Recovery of timber:
      Method used in removing safety posts______________
      Are timbers recovered?______________ How?______________
      Who supervises timber recovery?______________
   h. Timbering regulations:
      Are there systematic timbering rules?______________
         Verbal or printed?______________
         Is timbering outline provided?______________
         Are timbering rules strictly enforced?______________
   i. How is roof tested?______________ How often?______________

41. Explosives and blasting:
   a. Method of transporting explosives underground and to face______________
   b. Type of explosives car used______________
   c. Type of receptacle used for carrying and storing explosives underground______________
      Detonators______________
   d. Storage underground:
      How?______________
      Where?______________
   e. Maximum amount of explosives allowed miner per day______________
   f. Explosives:
      Kind for blasting coal______________
      Brushing______________
      Size and weight of cartridges______________

g. Detonators: Electric____
   Strength____
   Are ends of legs shorted?______________________________________

h. How, where, and when is primer made?______________________________
   ____

i. Firing method:
   By electricity from surface_____________________________________
   Electric power lines in mine____________________________________
   Battery_____________________ Kind____________________________
   Permissible_______________________Fuse_________________________
   Squibs____________________________If fuse or squib, how ignited?
   ____

j. Firing cables:
   Single or twin conductors______________________________________
   Condition, as to length____
   As to insulation____
   Is cable wound up after each shot or left strung out in gob or on timbers?____
   Is battery end of cable kept shorted?______________________________

k. Charge:
   Maximum and average amount________________ ____________________
   Distance apart and depth of holes (with total and respect to depth of cut)____
   Are mixed charges allowed?_______________________________________
   Position of primer in charge_____________________________________
   Direction detonator points_______________________________________
   Tool used for making hole in cartridge for detonator_____________
   ____

l. Loading holes:
   By whom____
   Are cartridges slit?____
   Is explosive rammed?____
   Are charges air-spaced?________________If so, how?______________
   ____
   How is hole cleaned out?

m. Stemming:
   Material used____
   Prepared in dummies_______________Length of dummies_____________
   Are holes stemmed to the collar?_________________________________
   Type of tamping bar____
   Is face region kept free from coal dust?____________________________

n. Blasting:
   By whom done, miner or shot firer_________________________________
   Number of shot firers____
   Are shot firers certified men, and what grade certificate?______
   ____
   Number of shots fired at one time________________________________
   Time of firing________________Are men out of mine?_______________
   Are tests for gas made before and following shooting?____________
   Are fire runs made after shooting?________________________________
   Is ample warning given before shooting?___________________________
   How?____

What precautions are taken when two places are coming together? ____________

If shot firers are used, do they make written report of amount of explosives used, condition, etc.? ____________

o. Are adjacent shots fired simultaneously? ____________
Are dependent shots fired? ____________
Are nearby shots fired in rapid succession? ____________

p. Do blown-out shots occur? ____________

q. Are bulldozing shots ever used? ____________

r. Misfires:
Care and method of examination ____________
Interval before return ____________
Method of removal ____________

s. Careless use or handling of explosives, detonators, fuse, squibs, etc. (Describe) ____________

t. If black blasting powder (granular, pellet, or stick) is used, describe method of handling ____________

u. Are open lights used near explosives? ____________

42. Ventilation and gas:

a. Volume of air:
Main intake ____________ Main return ____________
Number of splits ____________ Volume, each split ____________
Volume, last open crosscut on each split ____________

b. Aircourses:
Are they adequate in number and size? ____________
Obstructions (describe) ____________

c. Maximum number of men employed on one split of air ____________

d. General adequacy of air at working faces ____________

e. Line brattices:
Are they used in working places? ____________
Are they extended close enough to face? ____________
Is board used at top and bottom? ____________
Is there enough space between brattice and rib? ____________
Are brattices well-maintained? ____________

f. Crosscuts:
Maximum distance between ____________
Is more than one crosscut open between last stopping and face? ____________

g. Old workings:
Ventilated or securely sealed ____________
Type of seal ____________
Does air from old workings pass through working places? ____________
Method, if any, of relieving gas pressure behind seals ____________
Is provision made for sampling air behind seals? ____________
What is nature of atmosphere behind seals? ____________

h. Is a good ventilation map maintained?____________________
i. Booster and blower fans in mine:
Number__________Type____________________________________
Are fan intakes in fresh air?____________________________
Volume of air passing fan intake__________________________
Volume of air supplied by blower__________________________
Type of fan tubing_____________________________________
Condition____
j. Stoppings:
Material of construction, entries_________________________
Rooms____
Are stoppings well sealed into rib and roof?_________________
Are entry stoppings at intervals provided with small openings?
__________ Size of opening______________Type of door____
k. Overcasts:
Material of construction__________________________________
Are approaches easy or abrupt?_____________________________
l. Doors:
Number__________ Construction______________________________
Condition as to tightness_________________________________
On main haulageways_______________________________________
In pairs or singly____
Are doors equipped with latches?____________________________
What would be the effect or danger if doors were left open?_____
____
____
Are trappers employed?______________________________________
m. Regulators:
Number__________Type______________________________________
n. Is mine rated as gassy by State mining department?___________
o. Frequency of gas being reported_____________________________
p. May gas be liberated suddenly?_____________________________
Is mine free from standing gas?_____________________________
q. Is mine connected with a gassy or other mine?_________________
Name____
Is connection sealed or isolation otherwise afforded?__________
Describe____
____
r. Gas inspection and testing:
By whom?__________________When?____________________________
How reported?____
If gas is found, when and how is it removed?_________________
____
Do firebosses carry open lights or electric cap lamps when making inspections?______________________________________
Do firebosses use electric locomotives to travel in and out of mine?____
Number of certified firebosses______________________________
Type of flame safety lamps used______________________________
Maintained by whom?____

Are flame safety lamps examined and tested?__________
When?__________ How?__________
Do machinemen use flame safety lamps?__________
How are they trained in their use?__________

Type of methane detector used, if any__________
Is return air tested periodically?__________
Are places with standing gas fenced off?__________
Does fireboss leave evidence of his examination in each place?__________

Does fireboss record the results of his inspections?__________

s. Gas-ignition hazards:
Are locomotives, mining machines, pumps, or other electrical equipment operated on other than pure intake air?__________

Electric arcing or sparking, hazards from, if any__________

Is black blasting powder used?__________
Miners' lights, kind, number__________
Other mine illumination__________
Is smoking permitted underground?__________
Are men searched for smoking material?__________
Have accidents occurred from methane ignition?__________
Describe__________

t. Does the company regularly sample and analyze mine air?__________
Who analyzes samples?__________
Interpret and discuss analysis of air samples__________

43. Dust:

a. Accumulation of coal dust on roadways, rib, roof, timbers, or gob in working places (describe bad conditions)__________

b. Accumulation of coal dust on entries and aircourses (describe bad conditions)__________

c. Is coal used for track ballast?__________
d. Is coal topped above cars?__________
e. Are cars leaky?__________
f. Are ribs and roof dusty?__________ Dry or moist__________
g. Are roadways dry or wet?__________
h. Are accumulations of coal dust thoroughly removed?__________
How often?__________
i. Method of humidifying (describe)__________

j. Is water used to allay dust (at face, on mining machines while in use, on trips)?__________

Air samples

Bottle No.	Location	Time	Date	Ane-mometer reading	Area	Cu. ft. air per minute	CH_4 reading in detector or lamp

Dust samples

Can No.	Location	Date	Rib, roof or road dust	Rock-dusted area

k. Application of rock dust (describe in full)____________________

l. Samples and data as to incombustible (interpret and discuss analysis)____________________

44. Haulage underground:
 a. System of haulage:
  Main haulage____________________
  Other haulage____________________
 b. Grade, dips, curves, and alinement of track____________________
 c. Road beds:
  Ballasting material____________________
  Wet or dry____________________
  Cleanliness of road beds____________________
 d. Track: Gage____________________
  Weight of rails, main line______Side entries______Rooms______
  Splice bars____________________
  Tie plates, condition of____________________
 e. Ties:
  Material, size, spacing, condition of main line____________________
  Side entries____________________
  Rooms____________________
 f. Proper curves, rails properly fastened down____________________
 g. Switches:
  Type____________ Condition____________
  Clearance of throws and at switches____________________
  Blocking____________________
  Stumbling hazard of switch bar____________________
  Illumination____________________
 h. Frogs:
  Guard rails____________________
  Blocking____________________
 i. Derails or safety blocks, location and general description____________________
 j. Clearance (roof, rib, timbering, and trolley or power wires):
  On entries________In rooms________At partings________
  Is gob or other material stored on clearance side?____________
  Other stumbling hazards____________________
 k. Shelter holes:
  Distance apart____________Size____________
  How marked____________Are they kept clean?____________
 l. Underground hoists:
  Location and ventilation____________________

Type____
Safety (same information as for main hoist, guards, brakes, etc.)
____
____
____
Cleanliness____
Illumination____
Fire hazard and protection__________________________
Is electrical equipment properly grounded and fused?____________
Room hoists (describe hazards)______________________

m. Rope:
Condition and size__________________________________
How often inspected, oiled, and resocketed?_________
Is written record of inspection kept?_______________
Condition of rollers________________________________
If slope haulage, are effective drags used?_________

n. Locomotives:
Trolley, cable-reel, permissible battery, or combination__________
____
Number__________________Type________________________
Size____________________Voltage_____________________
General condition of________________________________
Headlights, condition of____________________________
Controller handle and covers fastened down__________
Are all motors equipped with gong?__________________
Condition of cables and wiring______________________
____
Condition of fuses, circuit breakers or switches____
____
Type of nips used___________________________________

o. Animal haulage:
Number and general condition of animals_____________
____
Underground stable: Location, cleanliness, ventilation, fire protection, illumination, water supply__________
____
____
____
Do animals carry lights?____________________________
Where does driver ride?_____________________________

p. Cars:
Material________________________Type________________
Capacity________________________Tightness___________
Brakes or sprags, safety and condition of___________
Type of couplings___________________________________
Are they heat-treated at regular intervals?_________

q. Maintenance of haulage equipment:
Good________________Fair________________Poor________

r. Illumination of haulageways:
Spacing of lamps____________________________________
Size of lamps_______________________________________
Are lamps safely installed?_________________________

s. Are trip lights used on rear of all trips?____________________
On front of all pushed trips of three cars or more?____________
On front and rear of rope trips?__________________________
t. How is haulage controlled (automatic block signals, dispatcher, or trapper)?____
How is too high speed prevented?__________________________
u. Blocking cars:
Type of car stops used at working faces_____________________
Are trips of cars left standing on entries blocked?____________
If so, how?____
v. Man-trips:
If locomotive-hauled, maximum speed________________________
Is trip in charge of an official?___________________________
Does trip come to full stop before men unload?______________
Are tools carried in same car with men?____________________
Are explosives carried on man-trips?_______________________
Do men get off moving trip?_______________________________
Is power cut off trolley wire or is it guarded at loading and unloading stations?____________________________________
Do men ride on trolley side?______________________________
Are rails, lumber, or other supplies hauled on man-trip?_______
If slope haulage, how is rope fastened to load?________________
____
Does rope rider or other official familiar with signals ride man-trip?____
Is a safety coupling provided?____________________________
Are safety couplings used?________________________________
Is there an inspection of rope, couplings, and hoisting engine daily?____
Other safety precautions taken____________________________
____
Are suitable waiting places with seats provided underground?___
____
w. Miscellaneous haulage hazards:
Cleanliness of haulageways________________________________
Do men travel haulageways or are manways provided?____________
____
Condition of manways______________________________________
Are gates provided where manway crosses haulageway?___________
Is there a runaround at each shaft landing?_________________
Do men or officials ride loaded trips?______________________
Do haulage employees jump on or off moving trips?_____________
Are flying switches permitted?____________________________
Is back-poling practiced?_________________________________
Is excessive nipping practiced?____________________________
Do brakemen run ahead of moving trips to throw switches and to open doors?____
Are trips pushed?____
What method is used to rerail cars?_________________________
Type of clothing worn by haulage employees___________________
Safety of position of trip rider on trip______________________

45. Electricity underground:

a. Transmission lines:

How are lines taken into mine (drill holes, shaft, through drift opening)?____________________

In intake or return airway?____________________

Are power wires over 650 volts in armored cables?__________

Are power wires properly installed on insulators?__________

Are armored cables frequently grounded?__________

Location of power wires with respect to trolley wires__________

____

Are power wires adequately guarded at points where men must pass under them?__________

Are power wires insulated where they pass through doors, curtains, etc.?__________

Contact hazards__________

Arcing hazards__________

Sectional switches__________

Location__________ Type__________

b. Trolley wires:

Is wire securely supported on insulated hangers?__________

Position and distance above and outside of track__________

Protection of crossings (describe)__________

Protection at other dangerous places__________

Fire hazard (contact with inflammable material)__________

Is wire on opposite side of track from clearance?__________

Is trolley wire sectionalized by cut-out switches?__________

Length of sections__________

Are trolley frogs and cut-out switches provided at branch roads?__________

Are terminals of trolley and feed wires cut off?__________

Are insulated turn buckles used?__________

Do trolley switches have insulated handles?__________

Are rails well-bonded?__________ Cross-bonded?__________

Distance between__________

c. Storage-battery equipment:

Are battery locomotives used?__________

Permissible type?__________

Maintained in permissible condition?__________

Other equipment__________

Location of charging station__________

Ventilation__________

Condition of__________

d. Telephone system:

Number and locations__________

Permissible type__________

Operating condition__________

Are telephone wires located near power wires?__________

e. Signaling system:

Describe system__________

____

____

Voltage on wires____

Source of power____

Sparking hazards____

Is transformer effectively grounded?________________________

f. Shot-firing circuit (if shots fired from outside mine) (describe)

____

____

g. Underground transformer station:

Location____

Construction____

Is fire door provided?________________________________

Ventilation____

Voltage, incoming__________________Outgoing______________

Properly grounded____

Is wiring properly installed?________________________

Fire hazard and protection____________________________

Contact hazard____

Cleanliness____

Is station kept locked?________________________________

h. Underground motor-generator station:

Location and description______________________________

Number M-G sets____________Voltage, alternating current________

Direct current________________Properly grounded______________

Switchboard, adequately guarded________________________

Rubber mat on floor________________________________

Circuit breakers and fuses____________________________

Fire hazard and protection____________________________

Is station kept locked________________________________

i. Circuit breakers:

Automatic or hand-operated____________________________

If automatic, are they properly adjusted?________________

If hand-operated, are they tied in the "in" position?__________

j. Coal-cutting equipment:

Number of machines__________Type_____________Voltage___________

Alternating current or direct current____________________

Are machines of permissible type?________________________

Are machines maintained in permissible condition?____________

Are machines provided with separate ground circuits?__________

Are machines properly fused?____________________________

Is guard provided for cutter chain?______________________

Are machines kept in good repair?________________________

Inspected by whom?________________________________

How often?____

Is inspection record kept?____________________________

If inspection forms used, procure and include copy__________

Is water used while cutting?____________________________

How attached to power wire______________________________

Give tabulation of defects observed on permissible equipment___

____

____

k. Cables:
Type used________________ Condition________________
How are temporary splices made?________________
____
How long are temporary splices used?________________
Are cable splices electrically and mechanically strong?________
Are permanent splices vulcanized?________________
Is permanent splicing done underground or on surface?________
____
Is a record kept of cable defects and repairs?________________

l. Pumps:
Number________________ Kind________________
Permissible type________________
Condition of wiring________________
Open or enclosed switches________________
Fuses________________ Properly grounded________________
Insulated platform provided________________
Gears properly guarded________________
Are pump and wiring protected from roof falls?________________
On intake or return airways________________

m. Mechanical loaders, conveyors, scrapers, etc.:
Give brief description of method of working________________
____
____
____
Kind________________ Number________________
Permissible type________________
Condition________________
Apparent hazards________________
Accidents________________
Number of men on crew________ Duties of each________________
____
Tons of coal per machine________________
Is water used on coal or machine?________________
Are machines grounded?________________
Type of switches________________
Fuses or circuit breaker________________
Is machine stopped frequently to test roof?________________
Illumination________________
Dustiness________________

n. Other electrical equipment:
Miscellaneous motors, etc.________________
____

o. Inspection of electrical system and equipment:
By whom, how often, how reported?________________
____

46. Fire protection underground:
a. Are there fire-protection pipe lines throughout the mine?________
b. Frequency of water taps________________
c. Is hose kept at stations underground?________________
How many stations?________________

d. Length and diameter of hose______________________________

e. Fire extinguishers:

Number and kind______________________________

Where located______________________________

f. Is water always available?______________________________

g. Are brattice cloth and other emergency fire-fighting equipment and supplies available?______________________________

47. Protective clothing:

a. Type of goggles used______________________________

Are they worn continuously underground?______________________________

b. Type of safety hats used______________________________

c. Safety shoes used______________________________

d. Other protective clothing______________________________

e. What has been injury-reduction experience since adopting protective clothing?______________________________

____

____

48. Miscellaneous hazards:

a. Mine fires (hazards, method of prevention, fire-fighting methods and equipment)______________________________

____

____

Is coal subject to spontaneous fires?______________________________

b. Flood hazard:

Is there an accumulation of water in adjoining mine?______________________________

Head of water________feet. Is barrier maintained?______________________________

Thickness________feet.

Are workings under stream or body of water?______________________________

Are openings subject to probable hazard from flood or cloudburst?______________________________

Are openings protected?______________________________

Method of approaching abandoned or standing workings filled possibly with water or gas______________________________

____

Are emergency escapeways maintained?______________________________

c. Tools:

Are miners required to provide full sets of tools?______________________________

Is periodic inspection of tools made?______________________________

By whom?______________________________

Were any faulty tools observed?______________________________

Length of ax handles, if used______________________________

d. Oil and gas wells:

Are there oil or gas wells penetrating coal measure?______________________________

Active____________________Abandoned______________________________

Are wells protected by coal pillars?______________________________

Size of pillar______________________________

Are abandoned wells properly filled?______________________________

Are wells accurately located on mine map?______________________________

e. Storage of oil and other inflammable material______________________________

____

f. Supplies and materials:
Carelessness in handling and storing timber, ties, rails, cap pieces, gob, etc., along track or in working places (describe) ______

g. Give data on any other hazards noted ______

GENERAL SAFETY CONDITIONS

49. Supervision and discipline:
a. What are your general impressions regarding type and character of officials from your observations of the appearance and operation of the mine, both inside and out? ______
b. How many men are working under each face boss? ______
c. How many times per day does he visit each working place? ______
What is the total daily number of visits made by the various officials to each working place? ______
d. Are they hurried in their visits because of size of territory, or do they have time to inspect each working place properly? ______
e. Do officials mark the date and their initials at face of each place visited? ______
f. When they give orders, do they insist that they be carried out by the men? ______
g. If men fail or refuse to carry out orders, are they disciplined in any way? ______
h. Are face bosses required to perform other than supervisory work? ______
i. Are face bosses certified men? ______
j. Does discipline appear to be good? ______
Fair? ______ Poor? ______
k. Do men appear to receive orders without resentment? ______
l. Are orders willingly carried out? ______

50. Safety organization:
a. Is a safety organization maintained? ______ Describe ______
b. Is a safety engineer or inspector employed? ______
c. Describe in detail methods used by company officials and miners' committees in maintaining and promoting interest of employees in safety ______
d. Does there appear to be a spirit of cooperation between the men and company officials relative to accident prevention? ______

e. Is there a spirit of rivalry between this mine and other mines of this same or other companies regarding accident prevention?_____

f. Is there a bonus system by which the officials or miners are rewarded for good accident records and penalized for poor accident records?_____

51. Safety rules and standards:
  a. Is there a definite set of mine rules or operating standards covering the general operations of the mine and the proper method of performing the various usual kinds of work?_____
  b. Are these rules printed?_____In what form?_____
  c. What method is used to acquaint employees with mine rules?_____
  d. Do the officials insist upon the enforcement of these rules?_____

52. Safety meetings:
  a. Are safety meetings held?_____How often?_____
  b. Do meetings include both men and officials?_____
  c. Are safety rallies, including women and children, held?_____ How often?_____
  d. What other means are used to maintain interest in safety?_____

53. Bulletin boards:
  a. Is a safety bulletin board provided?_____
  b. Are safety bulletins provided?_____
  c. In what other effective manner is safety literature distributed to miners?_____

54. First aid and mine rescue?
  a. How many men have been trained:
     First aid_____ Mine rescue_____
     Advanced mine rescue_____ Accident prevention_____
  b. Are men given additional training?_____
     How often?_____
  c. Are employees instructed in the use of barricades?_____
  d. Is there an underground hospital or first-aid station?_____
  e. Is adequate material provided?_____
  f. Nearest general hospital_____
  g. Breathing apparatus:
     Number_____Type_____
  h. Is apparatus in condition for wearing?_____
  i. How often tested?_____By whom?_____
  j. Condition and amount of supplies_____
  k. Number and type of gas masks_____
     Condition_____
  l. Are self-rescuers used?_____

m. Is a mine rescue-crew maintained?____________________
n. Does this mine have access to a joint or State-owned rescue-station?____________________
(Note: A report of privately owned mine rescue-station should be made on a special form provided for that purpose.)

55. Accidents:
a. What has been the accident experience for the last several years?____________________

Are accidents investigated?__________Method of reporting accidents____________________

b. Procure copy of accident records and accident costs, if possible, and discuss causes and give remedies for preventing each class of accidents____________________

56. Summary of safety conditions:
a. Stress points worthy of special commendation____________________

b. Give concise summary of conditions which appear unsafe____________________

(Note: Any features which bear upon safety and are out of the ordinary, whether in favor of or against safety, should be described fully.)

RECOMMENDATIONS

Recommendations should be brief, numbered, and in accordance with previously stated facts.

Use an introductory statement in recommendations proper stating that "the following recommended changes are believed vital to the safety of the mine, and can be carried out without undue expenditure or wide departure from present mining practice". In general, data on mining practice obtained from sources other than the investigator's own observation should be so indicated.

ACKNOWLEDGMENT

Acknowledgment should be made of courtesies extended by officials.

Name of person making report:

____

Title________________________

Approved:

____

APPENDIX

The appendix should include copies of dust and air analysis reports, map of mine, American Table of Distances for explosives magazine (if needed), and other notes of general interest.

SPECIAL NOTE.- This outline has been prepared to assist in the collection of data necessary to the writing of safety inspection reports and, it is believed, covers most conditions found in and around coal mines. It was compiled from suggestions made by many of the engineers and field safety instructors of the United States Bureau of Mines. It is not expected that all the data contained in the outline will be included in the report, but all possible data are needed for the preparation of an intelligent report. Detailed descriptions of methods, practices, and equipment are not essential unless some phase is outstanding. The report should call attention to unusually good practices as well as emphasize the hazards observed.

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Department of the Interior

UNITED STATES BUREAU OF MINES
John W. Finch, Director

INFORMATION CIRCULAR

THE JOSEPH A. HOLMES SAFETY ASSOCIATION AND ITS AWARDS

BY

D. Harrington

I.C. 6831
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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

THE JOSEPH A. HOLMES SAFETY ASSOCIATION AND ITS AWARDS[1]

By D. Harrington[2]

INTRODUCTION

Every few weeks United States newspapers of 25 or 30 years ago ran scare-heads telling of some mine disaster, which was a first-page attraction for a day or two and then was forgotten until another disaster occurred a few weeks later. Interspersed with these disasters were the so-called sniping mine accidents, causing the death of one or two mine workers. The summation of all types of mine fatalities usually exceeded 3,000 a year. In the period 1906-10, inclusive, there were 84 major explosion disasters (or about 17 per year) in United States coal mines; the fatalities resulting from those disasters numbered 2,388 for the 5-year period. These frightful catastrophies helped to cause the total number of fatalities in our coal mines for the 5 years (including the fatalities from major explosions) to reach the enormous total of 13,288, an average of 2,658 per year. In addition, some hundreds of other types of mining accidents swelled the annual fatality list to upwards of 3,000.

This admittedly deplorable condition created so much Nation-wide comment that Congress was impressed with the necessity of having something done by the Federal Government with a view to trying to halt at least some of the excessive loss of life in our mines; in consequence, the Bureau of Mines was created and began to function in July 1910.

The prevention of accidents and ill health in mining therefore was the keystone of the Bureau's inception; from the outset and until the present, the prevention of accidents and ill health in the mining and allied industries has been one of the most important parts of the work of the Bureau of Mines. As the work progressed, it was found that "accident prevention is a journey, rather than a destination" and that there is not, as yet, any royal road to safety in mining. Numerous types of accident-prevention activity were tested. In trying to bring about greater safety and to reduce ill health in the mining and allied industries the Bureau has found it to be good policy not to have "all of its eggs in one basket"; one of the most consistently helpful agencies in the numerous kinds of safety activities fostered by the Bureau is the Joseph A. Holmes Safety Association.

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6831."

2 Chief, Health and Safety Branch, U. S. Bureau of Mines.

FOUNDING AND ORGANIZATION

The Joseph A. Holmes Safety Association was founded in 1916 by 24 leading national organizations of the mining, metallurgical, and allied industries to commemorate the efforts of Dr. Joseph Austin Holmes, the first director of the United States Bureau of Mines, in trying to reduce accidents and ill health in the mining and allied industries and to promote the doctrines of safety and the conservation of life in those industries. Therefore, the Joseph A. Holmes Safety Association is a national association of national associations.

Several organizations have been voted into membership since the founding of the association in 1916; at present there are 29 member organizations, as follows:

American Association for the Advancement of Science
American Ceramic Society
American Chemical Society
American Federation of Labor
American Gas Association
American Institute of Chemical Engineers
American Institute of Mining and Metallurgical Engineers
American Mining Congress
American Red Cross
American Society for Testing Materials
American Society of Mechanical Engineers
Coal Mining Institute of America
Geological Society of America
Holmes Safety Association
International Railway Fuel Association
International Union of Mine, Mill, and Smelter Workers
Mine Inspectors Institute of America
Mining and Metallurgical Society of America
National Academy of Sciences
National Coal Association
National Safety Council
Personnel Research Federation
Smithsonian Institution
Society for the Promotion of Engineering Education
The Electrochemical Society
United Mine Workers of America
United States Bureau of Mines
United States Geological Survey
United States Public Health Service

The first annual meeting of the permanent organization was held in Washington, D. C., on March 4, 1916, and the following resolution was passed giving the objects of the association:

(1) The making of one or more annual awards with or without honorariums, to be known as the "Holmes Safety Award," for the encouragement of those originating, developing, and installing the most efficient safety devices, appliances, or methods in the mining, quarrying, metallurgical, and mineral industries, previous to the close of the preceding calendar year; these awards to be the result of reports and investigations made by the secretary and representatives of the Association.

(2) The awarding of suitable medals, from time to time, for personal heroism or distinguished service in the saving of life, in any branch of the mining, quarrying, metallurgical, and mineral industries.

It was the aim of the association to bring safety in the mining industry before the public and to stimulate the safety movement through giving suitable awards. To carry out this work a campaign was launched to raise a permanent fund of one hundred thousand dollars, the interest from this fund to be used for purchasing suitable awards annually. The late David T. Day, first secretary of the association, was largely instrumental in starting a campaign to raise this money during the latter part of 1916, but due to the entrance of the United States into the World War in 1917 and the pressing need for relief funds, only $11,000 was collected. This amount was invested, and the interest has been used to make the annual awards.

Inasmuch as the fundamental object of the association is commemoration of the name of the first director of the United States Bureau of Mines in connection with his efforts to forward health and safety in the mining and allied industries, the constitution of the organization stipulated that the Director of the Bureau of Mines should act as president. This has automatically caused its affairs to be associated very intimately with the health and safety work of the Bureau of Mines, and for several years the head of the safety work of the Bureau of Mines has been elected secretary of the association. The close connection between the J. A. Holmes Safety Association and the United States Bureau of Mines has been of mutual benefit, and the effects of these benefits have been felt not only by the two organizations but also by the mining and allied industries in the vast strides towards greater safety in mining; the safety awards of the association have placed before the industry the data on which the awards have been made, showing by actual accomplishments in safe operation of mining activities that mining, while perhaps afflicted with numerous safety handicaps, can be, and in many cases is, conducted almost as safely as nearly any other of the so-called hazardous types of industrial work.

HERO AWARDS

Although it was one of the original purposes of the association to issue awards for the perfection of safety devices, appliances, or methods it has been felt that such an award could not be made until the association has a larger endowment fund. Hence only awards for heroic service were issued from 1919 to 1927; in the latter year the association began to issue awards for

meritorious safety records, and at present such awards constitute the major activity of the organization and one which exercises a vital effect upon safety in the mining and allied industries.

The first awards made were announced by Dr. Van H. Manning, president of the association and Director of the United States Bureau of Mines, at the dedication of the buildings of the Bureau of Mines Experiment Station at Pittsburgh, Pa., on October 1, 1919. Sixteen gold medals were given for meritorious service in the saving and attempt to save life.

From 1919 to 1925, only one class of award (a gold medal) was given by the association, namely, that for an heroic act in connection with the mining and allied industries. After many cases were presented to the association it was decided to revise the schedule of award and make four classes, gold, silver, and bronze medals and certificates of honor, depending upon the degree of risk involved in performing the meritorious service; and it was decided that no award of this type should be made except to workers in the mining and allied industries for acts in which their lives had been risked or actually lost.

These awards for meritorious service, or hero awards as they are frequently called, have been given annually since 1919, and during the 16-year period 1919-1934, 186 awards were issued. The following table gives the distribution of these awards by years:

Year	Gold medals	Silver medals	Bronze medals	Certificates of honor	Total awards
1919	16				16
1920	7				7
1921	12				12
1922	5				5
1923	4				4
1924	5				5
1925	1				1
1926		1	2		3
1927	1		2		3
1928	3	2	10		15
1929	5	3		26	34
1930		1	14		15
1931	5	13	9	6	33
1932	2	7			9
1933	2	5	3	2	12
1934	4	8			12
Total	72	40	40	34	186

In a number of instances the persons performing the heroic acts have lost their lives; it has been the aim of the association to stress the taking of due safety precautions and use of good judgment in saving or attempt to save life, and in considering the merit of the cases presented, these features have been the deciding factor.

Due to limited space the details of the various cases cannot be presented, but the wording on the certificates given the individuals (and reproduced in this paper) contains a brief statement of the act. The men to whom these hero awards have been given have risked their own lives to save the lives of others by such acts as returning to the explosion zone to assist fellow workers, changing the course of ventilation to protect imprisoned miners at the time of fire, entering a burning shaft to attempt to warn fellow workers, working under dangerous roof conditions to release imprisoned men, and numerous other dangerous tasks. There is no question that the recipients of these awards have deserved the designation of "hero".

These heroic acts have been performed on a total of 84 occasions; 43 awards were made for service at 17 fires, 33 awards in connection with 13 explosions, and 110 awards in connection with 47 miscellaneous accidents.

The hero awards were distributed through 26 States as follows:

States	Occurrences	Awards
Alabama	2	2
Arizona	6	43
Arkansas	1	1
California	5	7
Colorado	6	7
Florida	1	1
Idaho	1	2
Illinois	3	5
Indiana	2	2
Kansas	1	4
Kentucky	1	2
Maryland	1	1
Michigan	2	2
Minnesota	2	2
Missouri	2	2
Montana	3	15
Nevada	1	1
New Mexico	2	2
Ohio	4	7
Oklahoma	5	10
Pennsylvania	12	33
Texas	3	7
Utah	1	1
Washington	1	1
West Virginia	7	14
Wyoming	9	12
	84	186

The greatest number of occurrences of explosions, fires, or accidents recognized by hero awards was in Pennsylvania, with 12, and Wyoming, second with 9.

The division of the awards according to industry is shown in the following table:

Industry	Gold medals	Silver medals	Bronze medals	Certificates of honor	Total awards
Coal	40	23	23		86
Metal	26	7	14	28	75
Nonmetal	2	-	-	-	2
Petroleum	4	10	2	6	22
Construction	-	-	1	-	1

Persons engaged in coal mining have received the largest number of awards and the class of awards given, namely, 40 gold, 23 silver, and 23 bronze medals, indicates that in general the hazards to persons engaged in these heroic acts have been greater than in other industries. The first awards made to persons in the petroleum industry were presented in 1931, and the 22 awards given in the 3 years 1931-33 were in connection with 4 fires and 9 miscellaneous accidents.

An alphabetical list of the names of the persons receiving the awards and the wording appearing on the certificates is given at the end of this paper.

Two of the men listed, E. L. Haas and Robert Stevenson, have received both silver and bronze medals for services they performed on two different occasions in the Kinloch mine of the Valley Camp Coal Co., Parnassus, Pa.

OTHER TYPES OF AWARD

Until 1927 the only awards given by the association were those for heroic acts, but on February 16, 1927, a special meeting of the board of directors was held to discuss classes of awards which could be made for persons or companies developing meritorious safety devices or methods or having exceptional safety records. A motion was passed that a certificate of honor be given as an award and that awards be made under the following three headings:

1. Safety devices
2. Safety methods
3. Exceptional safety records of mines or organizations.

At the meeting in 1927 four awards for exceptional safety records were made by the board of directors: To the Muncie mine, Federal Mining & Smelting Co., Baxter Springs, Kan.; the Ford Collieries Co., Curtisville, Pa.; the Speed open limestone-rock quarry, Louisville Cement Co., Speed, Ind.; and the No. 6 mine, United States Coal & Coke Co., Gary, W. Va.

Similar awards for meritorious safety records have been made annually since 1927, 283 such awards being made to mines, plants, companies, associations, or individuals in the mining and allied industries during the 8-year period 1927-34.

The awards were distributed as follows:

	1927	1928	1929	1930	1931	1932	1933	1934	Total
Coal mines or mining companies	2	4	5	10	8	28	33	40	130
Metal mines or mining companies	1	3	3	4	9	11	19	9	59
Nonmetallic mines or plants	-	2	1	1	7	1	4	6	22
Petroleum plants or companies	-	-	-	-	3	3	2	-	8
Quarries	1	-	-	-	3	-	-	1	5
Associations	-	-	-	1	2	1	-	1	5
Mills or smelters	-	-	-	1	-	1	-	1	3
Miscellaneous	-	-	-	-	-	1	-	2	3
Individuals									
Coal mining	-	-	2	-	3	8	17	9	39
Metal mining	-	-	-	1	2	2	1	-	6
Nonmetallic mining	-	-	-	-	1	1	-	1	3
Total awards	4	9	11	18	38	57	76	70	283

Grouping these awards by industries, coal mining is again in the lead with 171 awards, metal mining second with 69, nonmetallic third with 32, petroleum industry fourth with 8 and miscellaneous companies fifth with 3.

The awards were distributed by States as follows:

Alabama	13
Arizona	4
California	6
Colorado	9
Illinois	11
Indiana	3
Kansas	3
Kentucky	5
Louisiana	4
Michigan	29
Minnesota	13
Montana	2
New Mexico	4
New York	1
Ohio	16
Oklahoma	2
Pennsylvania	71
Tennessee	5
Utah	8
Virginia	7
Washington	2
West Virginia	26
Wyoming	14
Wisconsin	6
	264

Nineteen awards were made to companies and associations with mines or plants operated in various States throughout the United States that were not included under the distribution by States.

WINNERS OF HERO AWARDS

Here follows an alphabetical list of persons who have received hero awards from the association, with the number of the award and the year in which it was given. After this the hero awards are listed in numerical order, with the wording on the certificates which accompanied them:

Gold Medals

No.	Name	Year	No.	Name	Year
36	Anderson, William	1922	74	Keener, Davis	1929
72	Bellah, E. J.	1929	10	Keith, George Washington	1919
17	Beondich, Daniel	1920	11	Klaus, August	1919
18	Boardman, John Latson	1920	28	Krueger, K. P.	1921
175	Boyle, Robert J.	1934	12	Krum, Frank	1919
1	Brennan, Neal	1919	158	Lantz, Irl H.	1932
41	Carter, Frank	1923	177	Major, Benjamin F.	1934
19	Collins, James	1920	75	Marchello, Michael	1929
20	Conroy, Michael	1920	38	Martin, W. H.	1922
2	Cooney, Thomas	1919	178	McGilvra, John	1934
45	Cotton, Isaac	1924	43	McKiernan, William H.	1923
50	Culp, William	1925	13	Mitchell, Adam B.	1919
73	Daley, Zeno	1929	14	Mitchell, William G.	1919
21	Delmarh, Jacob	1920	22	Moore, James D.	1920
3	Dugan, Manus	1919	29	Murphy, Francis Henry	1921
58	DuPree, Amiel	1928	39	Murphy, James	1922
156	Ewing, Emory	1932	30	Ogilvie, Alex	1921
24	Farlin, Herbert	1921	47	Pahule, Louis	1924
4	Farmer, John Calvin	1919	48	Pavlisin, Michael	1924
25	Ferrington, William	1921	49	Phillips, Clifford	1924
5	Foltz, Clyde	1919	31	Pierce, Frank	1921
6	Frowen, Granite J.	1919	132	Power, Homer E.	1931
141	Fullmer, G. Elmo	1931	32	Reichert, George	1921
26	Gold, Thomas	1921	66	Roach, David	1928
27	Gregovich, John	1921	33	Robinson, Lasco	1921
7	Hardy, Samuel	1919	44	Rumpf, Peter	1923
126	Hedden, Elwin Arthur	1931	34	Ryan, Lew E.	1921
54	Hislop, Thomas	1927	173	Samaripa, Andres	1933
42	Hoy, Warren A.	1923	23	Sheridan, Peter	1920
37	Hudson, James	1922	15	Softcheck, Michael	1919
170	Jackson, Willie M.	1933	40	Springs, A. W.	1922
176	Jones, David H.	1934	136	Stephens, Eulus M.	1931
46	Jones, Eben W.	1924	76	Stubblefield, John	1929
8	Jones, Lewis Meredith	1919	69	Thompson, Louis	1928
127	Jones, Ora Otis	1931	16	Turner, Henry Clay	1919
9	Jones, Samuel	1919	35	Williams, Clarence	1921

Silver Medals

No.	Name	Year	No.	Name	Year
122	Barish, John	1931	131	McKenzie, Lee E.	1931
139	Bates, William Daniel	1931	79	Menz, George B.	1929
140	Boice, Walter F.	1931	159	Mossholder, George R.	1932
164	Carter, Loney	1933	144	Myers, Charles B.	1931
57	Cooley, Samuel	1928	171	Pascoe, Ronald L.	1933
154	Couch, Henry	1932	160	Regecz, John	1932
166	Davis, William Browning	1933	182	Soltis, John	1934
181	DelPero, Damiano	1934	161	Stevenson, Glenn L.	1932
109	Dilliplane, James	1930	137	Stevenson, Robert	1931
155	Engle, Jesse	1932	162	Tapley, Howard A.	1932
167	Fenick, Joseph	1933	53	Taylor, R. Doughty	1926
180	Flockhart, Adam	1934	145	Thompson, George	1931
169	Gonzales, Felipe Y.	1933	179	Todd, Paul Edward	1934
124	Haas, E. L.	1931	77	Truckenmiller, M. D.	1929
142	Hatcher, Robert	1931	146	Turner, Louis P.	1931
60	Henderson, H. H.	1928	147	Wells, Percy A.	1931
128	Kearney, Peter J.	1931	183	Whalen, Thomas	1934
157	Kilborn, Joseph M.	1932	184	Wilkes, William	1934
78	Lagios, John	1929	185	Zandran, Pio	1934
130	Mason, William	1931	186	Zorko, Rudolph, Sr.	1934

Bronze Medals

121	Able, C. N.	1931	143	Moore, Horace Preston	1931
106	Acoff, Andrew	1930	117	Murhamer, John J.	1930
163	Apgar, Morris E.	1933	64	McNeil, Hector	1928
107	Ashby, Randolph	1930	52	McNeil, John	1926
108	Cowan, William	1930	118	Ney, Harry Eugene	1930
123	Featheringham, Thomas	1931	65	Orten, A.	1928
51	Fetty, Lee	1926	119	Renn, Forrest A.	1930
110	Haas, Edward L.	1930	133	Roeder, Frank	1931
59	Hansen, H. M.	1928	172	Roush, Harry	1933
125	Hawkins, William E.	1931	67	Seed, Daniel	1928
111	Hogan, James	1930	135	Shramo, Andrew	1931
61	Hoover, Harry	1928	68	Skinner, Earl	1928
112	Jobes, E. R.	1930	134	Stayton, Jr., W. H.	1931
113	Kearney, John	1930	120	Stevenson, Robert	1930
129	Kirchdoerfer, Henry F.	1931	55	Trewartha, Thomas	1927
114	Lambert, Richard Lee	1930	70	Tyson, Thomas	1928
115	Lehman, Albert R.	1930	138	Vaughn, James A.	1931
62	Mason, Thomas	1928	174	Vavrek, John	1933
63	Matthews, Thomas	1928	71	Wallman, Basil	1928
116	McGuire, James	1930	56	Wilson, Grover	1927

Certificates of Honor

No.	Name	Year	No.	Name	Year
81	Avila, Paulina	1929	91	Luna, G.	1929
80	Avila, Jose	1929	152	Marchino, James Noble	1931
82	Ayabar, Aurellano	1929	94	McLean, Alexander	1929
148	Bady, Mike John	1931	92	Melendez, G.	1929
83	Burgess, Walter	1929	93	Melendez, Jesus	1929
165	Clark, Fred R.	1933	95	Mongo, S. L.	1929
84	Corral, Lazo	1929	96	Montes, Jocquin	1929
149	Daniels, George Ray	1931	97	Musso, Lorenzo	1929
150	Davison, Fred H.	1931	153	Olsen, Harold	1931
85	Espinosa, Dominto	1929	98	Ramos, Ricardo	1929
168	Galpin, W. F.	1933	99	Reyes, Jr., Arturo	1929
86	Gonzalez, S.	1929	100	Sanchez, Pedro	1929
151	Hadden, Henry M.	1931	101	Sobriano, G.	1929
87	Hernandez, Damian	1929	102	Soria, Pasqual	1929
88	Holquin, Luis	1929	103	Valdez, Juan	1929
89	Irigollen, Jose	1929	104	Valencio, Benino	1929
90	LeGrande, Fred	1929	105	Ybarra, Ycidrio	1929

JOSEPH A. HOLMES SAFETY ASSOCIATION

CITATIONS FOR HEROIC SERVICE

1919

1. NEAL BRENNAN (Gold)
who died attempting to save life,
Pennsylvania Mine, Butte, Montana
February 14, 1916.

2. THOMAS COONEY (Gold)
for saving life in Pennsylvania Mine,
Butte, Montana, February 14, 1916.

3. MANUS DUGAN (Gold)
who died after saving lives
of 27 miners, Speculator Mine,
Butte, Montana, June 8, 1917.

4. JOHN CALVIN FARMER (Gold)
who died in attempting the rescue
of two miners, Havaco, W. Va.,
December 21, 1918.

5. CLYDE FOLTZ (Gold)
who died attempting rescue
of imprisoned miners, Mt. Braddock, Pa.,
January 20, 1919.

6. GRANITE J. FROWEN (Gold)
for saving life in Pennsylvania Mine,
Butte, Montana, February 14, 1916.

7. SAMUEL HARDY (Gold)
who died attempting the rescue of
imprisoned miners, Mt. Braddock, Pa.,
January 20, 1919.

8. LEWIS MEREDITH JONES (Gold)
who died attempting to save imprisoned miners, Barrackville, W. Va.,
October 20, 1916.

9. SAMUEL JONES (Gold)
who died in mine attempting the
rescue of John Calvin Farmer,
Havaco, W. Va., December 21, 1918.

10. GEORGE WASHINGTON KEITH (Gold)
for hazardous risk taken in mine in effort to rescue John Calvin Farmer, Havaco, W. Va., Dec. 21, 1918.

11. AUGUST KLAUS (Gold)
for assisting the rescue of two imprisoned miners, Mt. Braddock, Pa., January 20, 1919.

12. FRANK KRUM (Gold)
for assisting the rescue of two imprisoned miners, Mt. Braddock, Pa., January 20, 1919.

13. ADAM B. MITCHELL (Gold)
for hazardous risk taken in mine assisting in rescue of G. W. Keith, Havaco, W. Va., December 21, 1918.

14. WILLIAM G. MITCHELL (Gold)
who died attempting to save life, Pennsylvania Mine, Butte, Montana, February 14, 1916.

15. MICHAEL SOFTCHECK (Gold)
for assisting the rescue of two imprisoned miners, Mt. Braddock, Pa., January 20, 1919.

16. HENRY CLAY TURNER (Gold)
for hazardous risk taken in mine assisting in rescue of G. W. Keith, Havaco, W. Va., December 21, 1918.

1920

17. DANIEL BEONDICH (Gold)
for rescue of miners from Belgrade Mine fire, Biwabik, Minnesota, February 1, 1919.

18. JOHN LATSON BOARDMAN (Gold)
for assisting in saving life of Frank Pierce and others in Leonard Mine fire, Butte, Montana, February 28, 1917.

19. JAMES COLLINS (Gold)
for hazardous risk taken to rescue Peter F. Grant and Emil Sayko, who, after 14 days' imprisonment, were rescued, Cold-Hunter Mine, Mullan, Idaho, November 21, 1919.

20. MICHAEL CONROY (Gold)
who died attempting to save lives of miners, Speculator Mine, Butte, Montana, June 8, 1917.

21. JACOB DELMARH (Gold)
for hazardous risk taken to rescue Peter F. Grant and Emil Sayko, who, after 14 days' imprisonment, were rescued, Gold-Hunter Mine, Mullan, Idaho, November 21, 1919.

22. JAMES D. MOORE (Gold)
who died after having saved the lives of six miners, Speculator Mine, Butte, Montana, June 8, 1917.

23. PETER SHERIDAN (Gold)
who died attempting to save lives of miners, Speculator Mine, Butte, Montana, June 8, 1917.

1921

24. HERBERT FARLIN (Gold)
for hazardous risk taken to save life following fire in Leonard Mine, Butte, Montana, February 28, 1917.

25. WILLIAM FERRINGTON (Gold)
who died attempting the rescue of William Webb and William Chowan, Shot Firers, Jackson-Walker Coal and Mining Company, Mine 17, Franklin, Kansas.

26. THOMAS GOLD (Gold)
for hazardous risk in assisting in removing William M. Quigley from electric current and resuscitating him - Folsom-Morris Mine, Lehigh, Oklahoma, January 31, 1916.

27. JOHN GREGOVICH (Gold)
for assisting in rescue of Frank Pierce, and other miners, Leonard Mine, Butte, Montana, February 28, 1917

28. K. P. KRUEGER (Gold)
for hazardous risk taken to save life, Leonard Mine, Butte, Montana, February 28, 1917

29. FRANCIS HENRY MURPHY (Gold)
who died attempting the rescue of William Webb and William Chowan, Shot Firers, Jackson-Walker Coal and Mining Company, Mine 17, Franklin, Kansas.

30. ALEX OGILVIE (Gold)
for hazardous risk in assisting in removing William M. Quigley from electric current and resuscitating him - Folsom-Morris Mine, Lehigh, Oklahoma, January 31, 1916.

31. FRANK PIERCE (Gold)
for hazardous risk taken to save life following fire in Leonard Mine, Butte, Montana, February 28, 1917.

32. GEORGE REICHERT (Gold)
for hazardous risk taken to save life following fire in Leonard Mine, Butte, Montana, February 28, 1917.

33. LASCO ROBINSON (Gold)
who lost his life while traveling through mine to warn miners of impending explosion that took his life, M. K. and T. Coal Company, Degnan, Oklahoma, August 21, 1920.

34. LEW. E. RYAN (Gold)
for hazardous risk taken to save life following fire in Leonard Mine, Butte, Montana, February 28, 1917.

35. CLARENCE WILLIAMS (Gold)
who lost his life while traveling through mine to warn miners of impending explosion that took his life, M. K. and T. Coal Company, Degnan, Oklahoma, August 21, 1920.

1922

36. WILLIAM ANDERSON (Gold)
for hazardous risk taken that led to the rescue of Peter McCall, William Martin, Thomas Griffiths, and Charles Fisher, following explosion, Mine 17, Jackson-Walker Coal & Mining Co., Frontenac, Kansas. November 2, 1918.

37. JAMES HUDSON (Gold)
who lost his life by suffocation while making effort to rescue Henry De Winter, who also lost his life by suffocation in Black Diamond Mine No. 2, Black Diamond, Washington. July 10, 1920.

38. W. H. MARTIN (Gold)
for the effort made to save R. A. Chapman, who died from the gases of the explosion, Parrish Mine, Alabama, November 23, 1920.

39. JAMES MURPHY (Gold)
for hazardous risk taken that led to the rescue of Peter McCall, William Martin, Thomas Griffiths, and Charles Fisher, following explosion, Mine 17, Jackson-Walker Coal & Mining Co., Frontenac, Kansas, November 2, 1918.

40. A. W. SPRINGS (Gold)
for resuscitating men overcome while exploring mine in search for live miners, Franklin Coal & Coke Co., Royalton, Ill., Explosion, October 27, 1914.

1923

41. FRANK CARTER (Gold)
who rescued James Jackson from dynamite fumes, Lincoln Colliery drainage tunnel, Rausch Creek, Pa. January 21, 1921.

42. WARREN A. HOY (Gold)
who lost his life in effort to rescue James Jackson from dynamite fumes, Lincoln Colliery drainage tunnel, Rausch Creek, Pa., January 21, 1921.

43. WILLIAM H. McKIERNAN (Gold)
who lost his life after rescuing Robert O. Anderson from black damp in a mine shaft, Kimberly, Missouri, July 18, 1919.

44. PETER G. RUMPF (Gold)
who assisted in the rescue of Frank Carter and John Payne from dynamite fumes, Lincoln Colliery drainage tunnel, Rausch Creek, Pa., January 21, 1921.

1924

45. ISAAC COTTON (Gold)
for recovery, from powder smoke and gases, of Logan and Murl Bedwell, whose clothes were ablaze. Jasonville Mine, Jasonville, Ind., April 18, 1923.

46. EBEN W. JONES (Gold)
who lost his life while attempting to give warning to four miners who also lost their lives by the collapse of the roof in Mount Jessup Mine, Peckville, Penn., December 8, 1923.

47. LOUIS PAHULE (Gold)
for assisting in the rescue of Chester Mott, who was overcome by gases from explosives in the Yak Mine, Leadville, Colo., October 3, 1923.

48. MICHAEL PAVLISIN (Gold)
for directing the barricading and saving of 21 miners from mine gases following explosion, Frontier, Wyo., August 14, 1923.

49. CLIFFORD PHILLIPS (Gold)
for assisting in barricading and saving of 21 miners from mine gases following explosion, Frontier, Wyo., August 12, 1923.

1925

50. WILLIAM CULP (Gold)
who lost his life in effort to rescue William A. Stoneberger in shaft of Detroit Rock Salt Company, Oakwood, Michigan, June 15, 1924.

1926

51. LEE PETTY (Bronze)
for directing 20 men to a place of safety following the explosion in the Jamison No. 8 mine, Farmington, W.Va., January 14, 1926, thus saving their lives.

52. JOHN McNEIL (Bronze)
for assisting in directing 20 men to a place of safety following the explosion in the Jamison No. 8 mine, Farmington, W.Va., January 14, 1926, thus saving their lives.

53. R. DOUGHTY TAYLOR (Silver)
for courageous attempt to protect a fellow employee, Oscar Harris, against impending danger, Attala Mine, Attala, Alabama, December 19, 1925.

1927

54. THOMAS HISLOP (Gold)
for directing 63 men to place of safety at risk of his life during a fire in the Mt. Lookout Mine, Wyoming, Pa., May 27, 1926.

55. THOMAS TREWARTHA (Bronze)
for service in maintaining discipline and directing work which contributed to the safety and rescue of 42 men imprisoned by a cave-in at the "G" Pabst Shaft, Ironwood, Michigan, September 24, 1926.

56. GROVER WILSON (Bronze)
for courageous attempt to save the life of L. C. Blair following explosion in No. 5 Mine, Eccles, W. Va., March 9, 1926.

1928

57. SAMUEL COOLEY (Silver)
for assisting in the successful rescue of three miners following an explosion in the No. 53 mine, Bethlehem Mines Corporation, Cokeburg, Pa., April 2, 1927.

58. AMIEL DuPREE (Gold)
for directing the recovery of and reviving John Patterson who had been overcome by gases from a fire in the No. 5 Mine, Osage Coal Co., Krebs, Okla., March 15, 1927.

59. H. M. HANSEN (Bronze)
same wording as A. Orten (no. 65).

60. H. H. HENDERSON (Silver)
for assisting in the successful rescue of three miners following an explosion in the No. 53 Mine, Bethlehem Mines Corporation, Cokeburg, Pa., April 2, 1927.

61. HARRY HOOVER (Bronze)
same wording as A. Orten (no. 65).

62. THOMAS MASON (Bronze)
same wording as A. Orten (no. 65).

63. THOMAS MATTHEWS (Bronze)
same wording as A. Orten (no. 65).

64. HECTOR McNEIL (Bronze)
for giving warning of impending danger, at personal risk, to 19 miners, resulting in their escape to higher ground at time of flooding of Old Wise mine, Old Wise Coal Co., Henryetta, Okla., April 14, 1927.

65. A. ORTEN (Bronze)
for assisting, at personal risk, in the rescue of Alfred Ramsen, who was overcome by gases in a raise, and dead when recovered, in the Junction mine, Calumet & Arizona Mining Co., Lowell, Arizona, February 28, 1927.

66. DAVID J. ROACH (Gold)
for successfully directing the rescue of three miners following an explosion in No. 53 mine, Bethlehem Mines Corporation, Cokeburg, Pa., April 2, 1927.

67. DANIEL SEED (Bronze)
for assisting, at personal risk, in the rescue of Alfred Ramsen who was overcome by gases in a raise, and dead when recovered, in the Junction mine, Calumet & Arizona Mining Co., Lowell, Arizona, February 28, 1927.

68. EARL SKINNER (Bronze)
same wording as A. Orten (no. 65).

69. LOUIS THOMPSON (Gold)
for his effort, at personal risk, to revive fire boss, McCann, who had been rendered unconscious by gases from a fire in the No. 5 mine, Osage Coal Co., Krebs, Okla., March 15, 1927.

70. THOMAS TYSON (Bronze)
same wording as A. Orten (no. 65).

71. BASIL WALLMAN (Bronze)
same wording as A. Orten (no. 65).

1929

72. E. J. BELLAH (Gold)
for remaining at his post as hoisting engineer while surrounded by fire and raising five men from the shaft of the Teejon mine, Gleeson, Arizona, May 6, 1928.

73. ZENO DALEY (Gold)
who lost his life by being lowered in the shaft into the fire zone while endeavoring to render assistance to save the lives of miners in No. 2 shaft, Magma Copper Company, Superior, Arizona, November 24, 1927.

74. DAVID KEENER (Gold)
for assisting in the recovery of and the saving of the life of fireboss McCann, overcome by mine fire gases, No. 5 mine, Osage Coal Co., Krebs, Oklahoma, March 15, 1927.

75. MICHAEL MARCHELLO (Gold)
for risking his life in descending the shaft and bringing to the surface four miners while the hoist room and surface structures were burning, Teejon mine, Gleeson, Arizona, May 6, 1928.

76. JOHN STUBBLEFIELD (Gold)
for assisting in the recovery of and the saving of the life of fireboss McCann, overcome by mine fire gases, No. 5 mine, Osage Coal Co., Krebs, Oklahoma, March 15, 1927.

77. M. D. TRUCKENMILLER (Silver)
for risking his life in returning to a pit in which twelve blasts had been prepared and fuses lighted and assisted in pulling eight fuses and thus saved the life of James C. Doonan who had fallen into the mill, Sunrise mine, Colorado Fuel and Iron Company, Sunrise, Wyoming, November 20, 1928.

78. JOHN LAGIOS (Silver)
same wording as M. D. Truckenmiller (no. 77).

79. GEORGE B MENZ (Silver)
same wording as M. D. Truckenmiller (no. 77).

Diplomas Only

HONORABLE MENTION AND INSIGNIA for assisting at personal risk in an effort to rescue Loftus and Cerna, miners, who were overcome and died from the effect of gases from explosives in the Joy Raise, Humbolt mine, of the Phelps Dodge Corporation, Morenci, Ariz., November 15, 1928:

80. JOSE AVILA
81. PAULINA AVILA
82. AURELLANO AYABAR
83. WALTER BURGESS
84. LAZO CORRAL
85. DOMINTO ESPINOSA
86. S. GONZALEZ
87. DAMIAN HERNANDEZ
88. LUIS HOLQUIN
89. JOSE IRIGOLLEN
90. FRED LeGRANDE
91. G. LUNA
92. G. MELENDEZ
93. JESUS MELENDEZ
94. ALEXANDER McLEAN
95. S. L. MONGE
96. JOCQUIN MONTES
97. LORENZO MUSSO
98. RICARDO RAMOS
99. ARTURO REYES, JR.
100. PEDRO SANCHEZ
101. G. SOBRIANO
102. PASQUAL SORIA
103. JUAN VALDEZ
104. BENINO VALENCIO
105. YCIDRIO YBARRA

1930

106. ANDREW ACOFF (Bronze) for assisting John J. Murhamer at personal risk to a place of safety when Murhamer was partially overcome by gases following an explosion in the Kinloch mine, Valley Camp Coal Company, Parnassus, Pennsylvania, March 21, 1929.

107. RANDOLPH ASHBY (Bronze)
for releasing Curtis Griffith from fallen roof material which resulted in a compound fracture of his leg and hauling him a half mile to the outside while himself having received a broken collar bone and body bruises by the same material, Swanton mine, Chapman Coal Mining Company, Barton, Maryland, July 17, 1929.

108. WILLIAM COWAN (Bronze)
for giving warning at personal risk in descending a shaft with headframe burning and effecting the escape of six men underground at the Terrible mine, Ilse, Colorado, November 6, 1928.

109. JAMES DILLIPLANE (Silver)
for personal risk taken in removing Clement Rochofskie from noxious gases and assisting in his resuscitation, Cameron Colliery, Susquehanna Collieries Company, Shamokin, Pennsylvania, December 22, 1927.

110. EDWARD L. HAAS (Bronze)
same wording as James Hogan (No. 111)

111. JAMES HOGAN (Bronze)
for directing men to place of safety at some personal risk following an explosion in the Kinloch mine, Valley Camp Coal Company, Parnassus, Pennsylvania, March 21, 1929.

112. E. R. JOBES (Bronze)
for directing men to place of safety at some personal risk following an explosion in the Kinloch mine, Valley Camp Coal Company, Parnassus, Pennsylvania, March 21, 1929.

113. JOHN KEARNEY (Bronze)
same wording as James Hogan (no. 111).

114. RICHARD LEE LAMBERT (Bronze)
for assisting at personal risk in the rescue of Alfred Ramsen who lost his life through suffocation by gases resulting from explosives in a raise in the Junction mine, Calumet and Arizona Mining Company, Lowell, Arizona, February 28, 1927.

115. ALBERT R. LEHMAN (Bronze)
for remaining at post of duty in presence of impending danger and assisting in the release and recovery of Wally Leshinskie who had been covered by a sudden caving of the roof, Cameron Colliery, Susquehanna Collieries Company, Shamokin, Pennsylvania, December 10, 1928.

116. JAMES McGUIRE (Bronze)
same wording as James Hogan (no. 111).

117. JOHN J. MURHAMER (Bronze)
same wording as James Hogan (no. 111).

118. HARRY EUGENE NEY (Bronze)
for remaining at post of duty in presence of impending danger and assisting in the release and recovery of Wally Leshinskie who had been covered by a sudden caving of the roof, Cameron Colliery, Susquehanna Collieries Company, Shamokin, Pennsylvania, December 10, 1928.

119. FORREST A. RENN (Bronze)
for remaining at post of duty in presence of impending danger and assisting in the release and recovery of Wally Leshinskie who had been covered by a sudden caving of the roof, Cameron Colliery, Susquehanna Collieries Company, Shamokin, Pennsylvania, December 10, 1928.

120. ROBERT STEVENSON (Bronze)
same wording as James Hogan (no. 111).

1931

March 5

121. C. N. ABLE (Bronze)
for assembling a group of miners and directing the construction of a barricade for their protection following an explosion in the mine of the C.C.B. Smokeless Coal Company, Stotesbury, W. Va., December 27, 1929.

122. JOHN BARISH (Silver)
for assisting at great personal risk in the release of a miner imprisoned under a fall of roof material in the Kinloch mine, Valley Camp Coal Company, Parnassus, Pa., September 9, 1930.

123. THOMAS FEATHERINGHAM (Bronze)
for assisting in regulating mine ventilation and directing a large number of miners to places of safety during a fire in the mine of the Warner Collieries Company, Wolf Run, Ohio, March 10, 1930.

124. E. L. HAAS (Silver)
for assisting at great personal risk in the release of a miner imprisoned under a fall of roof material in the Kinloch mine, Valley Camp Coal Company, Parnassus, Pa., September 9, 1930.

125. WILLIAM E. HAWKINS (Bronze)
for assisting, at personal risk, in the rescue of Alfred Ramsen who was overcome by gases in a raise, and dead when recovered, in the Junction mine, Calumet and Arizona Mining Company, Lowell, Ariz., February 28, 1927.

126. ELWIN ARTHUR HEDDEN (Gold)
for taking great personal risk in traveling a long distance to give warning to two fellow miners against an inrush of water, thus saving them from drowning in the mine of the Leyden Lignite Company, Leyden, Colorado, October 13, 1928.

127. ORA OTIS JONES (Gold)
for the release of a fellow workman from under fallen roof material and giving him treatment that saved his life while suffering from injuries himself and at serious personal risk, Tidewater mine, The Koppers Coal Company, Vivian, W. Va., November 1, 1930.

128. PETER J. KEARNEY (Silver)
for assisting, at personal risk, in the release of a miner imprisoned under a fall of roof material in the Kinloch mine, Valley Camp Coal Company, Parnassus, Pa., September 9, 1930.

129. HENRY F. KIRCHDOERFER (Bronze)
for assembling and leading a group of miners to a place of safety while a flood of water entered the Tomhicken mine of Coxe Brothers & Company, Inc., Luzerne County, Pa., November 16, 1926.

130. WILLIAM MASON (Silver)
for assisting, at personal risk, in the release of a miner imprisoned under a fall of roof material in the Kinloch mine, Valley Camp Coal Company, Parnassus, Pa., September 9, 1930.

131. LEE E. McKENZIE (Silver)
for risking his life in an unsuccessful effort to save the life of a miner who was asphyxiated by gases of an explosive, Minnewas open pit, Oliver Iron Mining Company, Virginia, Minn., February 5, 1927.

132. HOMER E. POWER (Gold)
for risking his life in descending a smoke-filled shaft as the result of a fire and effecting the rescue of two miners in the No. 1 mine, The Grasselli Chemical Company, Waco, Missouri, May , 1927.

133. FRANK ROEDER (Bronze)
for assisting in regulating mine ventilation and directing a large number of miners to places of safety during a fire in the mine of the Warner Collieries Company, Wolf Run, Ohio, March 10, 1930.

134. W. H. STAYTON, JR. (Bronze)
for assisting, at personal risk, in the rescue of Alfred Ramsen who was overcome by gases in a raise, and dead when recovered, in the Junction mine, Calumet and Arizona Mining Company, Lowell, Ariz., February 28, 1927.

135. ANDREW SHRAMO (Bronze)
for assisting in regulating mine ventilation and directing a large number of miners to places of safety during a fire in the mine of the Warner Collieries Company, Wolf Run, Ohio, March 10, 1930.

136. EULUS M. STEPHENS (Gold)
for the rescue from drowning of a fellow workman following a rush of water from a broken impounding dam, American Agricultural Chemical Company, Pierce, Florida, September 25, 1928.

137. ROBERT STEVENSON (Silver)
for assisting at great personal risk in the release of a miner imprisoned under a fall of roof material in the Kinloch mine, Valley Camp Coal Company, Parnassus, Pa., September 9, 1930.

138. JAMES A. VAUGHN (Bronze)
for assembling a group of miners and directing the construction of a barricade for their protection following an explosion in the mine of the C.C.B. Smokeless Coal Company, Stotesbury, W. Va., December 27, 1929.

June 30

139. WILLIAM DANIEL BATES (Silver) for risking his life on August 28, 1927, in three attempts to rescue a fellow workman of the Shell Petroleum Corporation, who was unconscious in an atmosphere deficient in oxygen in a well 42 feet deep, Wood River, Ill.

140. WALTER F. BOICE (Silver) in recognition of his service, on the occasion of a fire at the Los Nietos gasoline plant, Kettleman Hills, California, in 1930, when at great personal risk, he went into the burning plant and, with others, brought out an employe trapped inside and who died subsequently.

141. G. ELMO FULLMER (Gold) in recognition of excellent leadership on the occasion of a fire at the Los Nietos gasoline plant, Kettleman Hills, Calif., in 1930, when, at great personal risk, he went into the burning plant and, with others, brought out an employe trapped inside and who died subsequently.

142. ROBERT HATCHER (Silver) in recognition of his effort, assisted by others, at serious personal risk, to rescue C. E. Curry, a fellow employe, who, on November 6, 1929, fell into an empty oil-storage tank containing hydrogen sulphide gas at the Borger, Texas, plant of the Gulf Production Company; Hatcher being overcome by the gas and Curry being subsequently removed dead.

143. HORACE PRESTON MOORE (Bronze) for incurring considerable personal risk on November 7, 1930, in saving the life of a fellow workman of the Shell Petroleum Corporation, who was overcome by gas while working on a stack 160 feet high, Wood River, Ill.

144. CHARLES B. MYERS (Silver)
in recognition of his effort, assisted by others, at serious personal risk, to rescue C. E. Curry, a fellow employe, who, on November 6, 1929, fell into an empty oil-storage tank containing hydrogen-sulphide gas at the Borger, Texas, plant of the Gulf Production Company; Myers being overcome by the gas and Curry being subsequently removed dead.

145. GEORGE THOMPSON (Silver)
in recognition of his service on the occasion of a fire at the Los Nietos gasoline plant, Kettleman Hills, California, in 1930, when at great personal risk, he went into the burning plant and, with others, brought out an employe trapped inside and who died subsequently.

146. LOUIS P. TURNER (Silver)
in recognition of his effort, assisted by others, at serious personal risk, to rescue C. E. Curry, a fellow employe, who, on November 6, 1929, fell into an empty oil-storage tank containing hydrogen-sulphide gas at the Borger, Texas, plant of the Gulf Production Company; Turner losing his life and Curry being subsequently removed dead.

147. PERCY A. WELLS (Silver)
in recognition of his effort, assisted by others, at serious personal risk, to rescue C. E. Curry, a fellow employe, who, on November 6, 1929, fell into an empty oil-storage tank containing hydrogen-sulphide gas at the Borger, Texas, plant of the Gulf Production Company; Wells being overcome by the gas and Curry being subsequently removed dead.

Certificates of Honor

June 30, 1931

148. MIKE JOHN BADY
for incurring personal risk on August 28, 1927, in attempting to rescue a fellow workman of the Shell Petroleum Corporation who was unconscious in an atmosphere deficient of oxygen in a well 42 feet deep.

149. GEORGE RAY DANIELS
for incurring the personal risk of being overcome by gas in rescuing a fellow workman, who was unconscious in a tank car at the East Chicago Refinery of the Shell Petroleum Corporation, on April 16, 1929.

150. FRED H. DAVIDSON
for risking his life to help carry a fellow workman out of the fire zone at the time of a fire in the cracking coil department of the Standard Oil Company near Cleveland, Ohio, on June 30, 1930.

151. HENRY M. HADDEN
for risking his life to help carry a fellow workman out of the fire zone at the time of a fire in the cracking coil department of the Standard Oil Company near Cleveland, Ohio, on June 30, 1930.

152. JAMES NOBLE MARCHINO
for incurring personal risk on August 28, 1927, in attempting to rescue a fellow workman of the Shell Petroleum Corporation who was unconscious in an atmosphere deficient of oxygen in a well 42 feet deep.

153. HAROLD OLSEN
for risking his life in rescuing a fellow workman of the Sinclair Oil & Gas Company who had fallen into a tank car containing a high concentration of petroleum vapors, near Seminole, Oklahoma, July 18, 1930.

1932

154. HENRY COUCH
A Silver Medal of Honor
for seriously risking his life in assisting in the successful rescue of a blasting foreman who was caught under falling roof material in the mine of the Ajax Coal Company, Bulan, Kentucky, July 26, 1931.

155. JESSE ENGLE
A Silver Medal of Honor
for seriously risking his life in assisting in the successful rescue of a blasting foreman who was caught under falling roof material in the mine of the Ajax Coal Company, Bulan, Kentucky, July 26, 1931.

156. EMORY EWING
A Gold Medal of Honor
for his courage in putting his life in grave jeopardy in rescuing a fellow-worker from a fire at a gasoline storage station of the Union Oil Company at Visalia, California, December 29, 1930.

157. JOSEPH M. KILBORN
A Silver Medal of Honor
for returning at risk of his own life to rescue his fellow-worker after having at one time escaped from hydrogen sulphide and other fumes by which both had been overcome while drilling for the Gulf Production Company, Crane County, Texas, December 4, 1931.

158. IRL H. LANTZ
A Gold Medal of Honor
for his courage in risking his life in the rescue of a fellow worker who was in flames as a result of attempting to extinguish a gasoline fire, the Simms Oil Company, Smackover, Ark., September 1, 1929.

159. GEORGE R. MOSSHOLDER
A Silver Medal of Honor
for his resourcefulness and courage in risking his life in rescuing his fellow-worker overcome by hydrogen sulphide and other fumes while drilling a well for the Gulf Production Company, Crane County, Texas, December 4, 1931.

160. JOHN REGECZ
A Silver Medal of Honor
for risking his life three times in successfully rescuing a fellow workman whose head had been caught and was held between two charged trolley wires in the Walhonding Mine, Cambridge Collieries Company, Buffalo, Ohio, January 20, 1932.

161. GLENN L. STEVENSON
A Silver Medal of Honor
for his resourcefulness in administering first aid with resultant saving of the life of a fellow-worker while both were caught under a fall of roof in the coal mine of the Columbia Steel Company, Columbia, Utah, February 7, 1931.

162. HOWARD A. TAPLEY
A Silver Medal of Honor
for his courageous efforts on October 3, 1929, at Signal Hill, California, in the removal of a fellow lineman of the Shell Oil Company from a pole after he had come in contact with electric current and had his clothing ablaze.

1933

163. MORRIS E. APGAR
A Bronze Medal of Honor
for incurring considerable personal risk on February 10, 1932, in saving the life of a fellow workman of the Hoover Dam project who had come in contact with a 2,300-volt switch on an electric shovel.

164. LONEY CARTER
A Silver Medal of Honor
for risking his life in an improvised tunnel in the Powellton No. 4 Mine, on September 9, 1931, while assisting in the release of Alstock Potter whose arms were held securely by a fall of slate.

165. FRED R. CLARK
This Certificate of Honor
for prompt and effective assistance given in removing the flaming oil-soaked clothes of a fellow torch cutter in the scrap yard of the Colorado Fuel and Iron Company, Pueblo, Colorado, May 9, 1932, thereby preventing serious injury or possible death.

166. WILLIAM BROWNING DAVIS, M.D.
A Silver Medal of Honor
for risking his life in an improvised tunnel in the Powellton No. 4 Mine, on September 9, 1931, while amputating the arm of Alstock Potter, thereby saving Mr. Potter's life as his arm was securely held by a fall of slate.

167. JOSEPH FENICK
A Silver Medal of Honor
for risking his life to release a fellow workman who was imprisoned by a fall of rock in the No. 9 Mine, Carrolltown Coal Company, St. Benedict, Pa., January 9, 1933.

168. W. F. GALPIN
This Certificate of Honor
for prompt and effective assistance given in removing the flaming oil-soaked clothes of a fellow torch cutter in the scrap yard of the Colorado Fuel and Iron Company, Pueblo, Colorado, May 9, 1932, thereby preventing serious injury or possible death.

169. FELIPE Y. GONZALES
A Silver Medal of Honor
for risking his life to warn a fellow workman of impending danger of suffocation due to a fire in the No. 5 Mine, Gallup American Coal Company, Gamerco, New Mexico, on February 11, 1931.

170. WILLIE M. JACKSON
A Gold Medal of Honor
for the heroic rescue of a fellow-lineman from bare high-tension electric wires at the Sun Oil Company's lease at Mont Belvieu, Tex., August 23, 1930.

171. RONALD L. PASCOE
A Silver Medal of Honor
for risking his life in rescuing and carrying an unconscious fellow-worker through approximately 4,000 feet of gassy partly flooded workings in the Pennsylvania Shaft, at Grass Valley, California, January 24, 1933.

172. HARRY ROUSH
A Bronze Medal of Honor
for his good judgment and courage in leading to safety three men who were trapped in an atmosphere of ammonia gas in the basement of the Revloc Supply Company, Revloc, Pa., August 23, 1932.

173. ANDRES SAMARIPA
A Gold Medal of Honor
for risking his life to save two men who were overcome by poisonous gas resulting from an explosion in the Morgan-Jones Mine, Madrid, New Mexico, December 7, 1932.

174. JOHN VAVREK
A Bronze Medal of Honor
for the rescue, at considerable personal risk, of two unconscious boys from the interior of a gasoline tank car in the Erie Railroad Yards, Cleveland, Ohio, July 27, 1932.

1934

175. ROBERT J. BOYLE (Deceased)
A Gold Medal of Honor
for heroic work with resultant sacrifice of his life in attempting to rescue a fellow-worker who was overcome by irrespirable gases in a coal mine near Littleton, Colorado, December 1, 1933.

176. DAVID H. JONES
A Gold Medal of Honor
for heroic assistance in the saving of the life of a fellow-worker in the Open Pit of the United Verde Copper Company, Jerome, Arizona, May 4, 1933.

177. BENJAMIN F. MAJOR
A Gold Medal of Honor
for heroic assistance in the saving of the life of a fellow-worker in the Open Pit of the United Verde Copper Company, Jerome, Arizona, May 4, 1933.

178. JOHN McGILVRA
A Gold Medal of Honor
for heroic work in saving the life of a fellow-worker in the North Star Mine, Grass Valley, California, March 14, 1933.

179. PAUL EDWARD TODD
A Silver Medal of Honor
for risking his life in attempting to save a fellow-worker from drowning in the shaft of the Ellis Mine, near Cripple Creek, Colorado, June 14, 1933.

180. ADAM FLOCKHART
A Silver Medal of Honor
for risking his life while directing and aiding in the saving of the lives of two underground workers in the "C" Mine of The Union Pacific Coal Company, Superior, Wyoming, May 9, 1933.

181. DAMIANO DELPERO
A Silver Medal of Honor
for assisting, at considerable personal risk, in saving the lives of two fellow-workers in the "C" Mine of The Union Pacific Coal Company, Superior, Wyo., May 9, 1933.

182. JOHN SOLTIS
A Silver Medal of Honor
Same wording as Damiano DelPero (no. 181).

183. THOMAS WHALEN
A Silver Medal of Honor
Same wording as Damiano DelPero (no. 181).

184. WILLIAM WILKES
A Silver Medal of Honor
Same wording as Damiano DelPero (no. 181).

185. PIO ZANDRAN
A Silver Medal of Honor
Same wording as Damiano DelPero (no. 181).

186. RUDOLPH ZORKO, SR.
A Silver Medal of Honor
Same wording as Damiano DelPero (no. 181).

Here follows a list of recipients of the safety awards alphabetically arranged and giving the number of the award and the year it was made, after which is a list of the wordings on the certificates presented in connection with the safety awards arranged in numerical order:

JOSEPH A. HOLMES SAFETY AWARDS

Coal Mines and Mining Companies

Safety Award No.	Name	Year		
S.A. 214-------	Alabama By-Products Corporation, Flat Creek Division			('34)
S.A. 5---------	Alleghony Pittsburgh Coal Company, Springdale Mine			('28)
S.A. 138-215---	American Coal Company of Allegany County, Crane Creek Mine		('33)	('34)
S.A. 43--------	American Rolling Mill Company, Nellis Mine			('31)
S.A. 139-------	American Rolling Mill Company, Nellis Mine, Haulage and Transportation Department			('33)
S.A. 44--------	Bell and Zoller Coal and Mining Company, No. 2 Mine			('31)
S.A. 140-216---	Bell and Zoller Coal and Mining Company, Zeigler No. 1 Mine		('33)	('34)
S.A. 217-------	Bethlehem Mines Corporation			('34)
S.A. 14--------	Bethlehem Mines Corporation, Johnstown Division			('29)
S.A. 218-------	Bethlehem Mines Corporation, No. 51 Mine			('34)
S.A. 81--------	Bethlehem Mines Corporation, No. 71 Mine			('32)
S.A. 82--------	Bird Coal Company			('32)
S.A. 142-------	Black Diamond Coal Mining Company ...			('33)
S.A. 143-------	Block Coal & Coke Company, Block No. 1 Mine			('33)
S.A. 83--------	Buckeye Coal Company, Brier Hill Mine			('32)
S.A. 144-219---	Butler Consolidated Coal Company, Wildwood Mine		('33)	('34)
S.A. 84-145-220	Calumet Fuel Company, Somerset Mine .	('32)	('33)	('34)
S.A. 221-------	Clearfield Bituminous Coal Corporation			('34)
S.A. 146-------	Colonial Colliery Company			('33)
S.A. 222-------	Colorado Fuel and Iron Company, (Coal Mining Department)			('34)
S.A. 6---------	Colorado Fuel and Iron Company, Robinson No. 1 Mine			('28)
S.A. 147-------	Colorado Fuel and Iron Company, Crested Butte Mine			('33)

Safety Award No.	Name	Year
S.A. 148--------	Colorado Fuel and Iron Company, Rockvale No. 3 Mine	('33)
S.A. 45---------	Consolidation Coal Company, Elkhorn Division	('31)
S.A. 25---------	Consolidation Coal Company, West Virginia Division	('30)
S.A. 149--------	Consumers Mining Company, Steubenville Mine	('33)
S.A. 223--------	Darby Coal Company	('34)
S.A. 150--------	Davis Coal and Coke Company, Orenda Mine	('33)
S.A. 85---------	DeBardeleben Coal Corporation	('32)
S.A. 46---------	DeBardeleben Coal Corporation, Hull Mine	('31)
S.A. 26---------	DeBardeleben Coal Corporation, Western Division	('30)
S.A. 86---------	Ebensburg Coal Company, Ebensburg No. 1 Mine	('32)
S.A. 87-151-224	Electro-Metallurgical Company, Alloy Mine	('32) ('33) ('34)
S.A. 141--------	Ellsworth Collieries Company, Mine 51	('33)
S.A. 88---------	Ellsworth Collieries Company, Mine 58	('32)
S.A. 89---------	Empire Coal Mining Company, Empire "A" Mine	('32)
S.A. 1----------	Ford Collieries Company	('27)
S.A. 225--------	Hanna Coal Company of Ohio	('34)
S.A. 226--------	Harlan-Wallins Coal Corporation	('34)
S.A. 227--------	Harleigh Brookwood Coal Company, Lawrence Colliery	('34)
S.A. 90---------	Hotchkiss Coal Company, Hotchkiss Mine	('32) ('34)
S.A. 152-228---	Jamison Coal & Coke Company, No. 20 Mine	('33) ('34)
S.A. 153--------	Kemmerer Coal Company, Elkol Mine ...	('33)
S.A. 91---------	Liberty Fuel Company, Liberty Mine ..	('32)
S.A. 229--------	Lincoln Gas Coal Company	('34)
S.A. 230--------	Linton-Summit Coal Company, Haulage Department, No. 1 Mine	('34)
S.A. 15---------	Madison Coal Corporation, No. 12 Mine	('29)
S.A. 231--------	Mary Helen Coal Corporation	('34)
S.A. 232--------	Mill Creek Coal Company, Morea Colliery	('34)
S.A. 233--------	National Mining Company, National No. 1 Mine	('34)
S.A. 234--------	Nellis Coal Corporation, Nellis Mine, Haulage Force	('34)
S.A. 235--------	Nellis Coal Corporation, Nellis Mine, Tipple Force	('34)

Safety Award No.	Name	Year
S.A. 27--------	Newcastle Coal Company, No. 2 and No. 6 Mines	('30)
S.A. 236-------	Norfolk and Western Railway, Vulcan Colliery, Fuel Department	('34)
S.A. 154-------	Northwestern Improvement Company, Rosebud Mine	('33)
S.A. 28--------	Odin Coal Company, Odin Mine	('30)
S.A. 16--------	O'Gara Coal Company	('29)
S.A. 92--------	Pacific Coast Coal Company, Carbonado Mine	('32)
S.A. 155-------	Pacific Coast Coal Company, New Black Diamond Mine	('33)
S.A. 47--------	Peabody Coal Company, No.19 Mine	('31)
S.A. 156-------	Peale, Peacock, & Kerr, Inc.	('33)
S.A. 93--------	Penelec Coal Corporation	('32)
S.A. 157-------	Penn Run Coal Corporation, Victor No. 45 Mine	('33)
S.A. 94--------	Pennsylvania Coal and Coke Corporation, Ehrenfeld No. 8 Mine	('32)
S.A. 95--------	Pennsylvania Coal and Coke Corporation, No. 17 Colliery	('32)
S.A. 96--------	Phelps Dodge Corporation, No. 1 Mine.	('32)
S.A. 7---------	Phelps Dodge Corporation, No. 6 Mine.	('28)
S.A. 29--------	Phelps Dodge Corporation, Stag Canon Branch	('30)
S.A. 97--------	Philadelphia and Reading Coal and Iron Company, Brookside Colliery ..	('32)
S.A. 158-------	Philadelphia and Reading Coal and Iron Company, Hammond Mine	('33)
S.A. 237-------	Philadelphia and Reading Coal and Iron Company, Monitor Stripping....	('34)
S.A. 48--------	Pickands, Mather and Company, Mather Mine	('31)
S.A. 238-------	Pine Hill Coal Company	('34)
S.A. 49--------	Pocahontas Fuel Company, Sagamore Mine	('31)
S.A. 239-------	Railway Fuel Company, Parrish Mine ..	('34)
S.A. 8-50------	Rainey Incorporated, W. J., Stewart Mine	('28) ('31)
S.A. 30--------	Rochester and Pittsburgh Coal Company, Adrian Mine	('30)
S.A. 98--------	Rochester and Pittsburgh Coal Company, Soldier No. 1 Mine	('32)
S.A. 99--------	Rockhill Coal and Iron Company, Rockhill No. 8 Mine	('32)
S.A. 159-------	Rockhill Coal and Iron Company, Rockhill No. 9 Mine	('33)
S.A. 240-------	Scranton Coal Company	('34)

Safety Award No.	Name	Year		
S.A. 31----------	Shamrock Coal Company, Shamrock Mine			('30)
S.A. 32-241------	Sheridan Wyoming Coal Company		('30)	('34)
S.A. 100---------	Sheridan Wyoming Coal Company, Inc., Monarch Mine No. 45			('32)
S.A. 33----------	Skelly Coal Company, W. B., Elizabeth Mine			('30)
S.A. 242---------	Sloss-Sheffield Steel and Iron Company, By-Product Plant			('34)
S.A. 101-160-243	South Union Coal Company, South Union Mine	('32)	('33)	('34)
S.A. 161---------	Springfield Coal Corporation, Springfield No. 1 Mine			('33)
S.A. 162-244----	St. Clair Coal Company		('33)	('34)
S.A. 245---------	Stonega Coke and Coal Company, Arno Colliery			('34)
S.A. 163---------	Stonega Coke and Coal Company, Imboden Mine			('33)
S.A. 164---------	Stonega Coke and Coal Company, Roda Colliery			('33)
S.A. 165-246----	Stonega Coke and Coal Company, Stonega Coke Works		('33)	('34)
S.A. 247---------	Stonega Coke and Coal Company, Stonega Mine			('34)
S.A. 34----------	Superior Coal Company			('30)
S.A. 102---------	Taylor and McCoy Coal and Coke Company, Gallitzin Mine			('32)
S.A. 166---------	Union Pacific Coal Company			('33)
S.A. 248---------	Union Pacific Coal Company, No. 1 Mine			('34)
S.A. 103-249----	Union Pacific Coal Company, No. 4 Mine		('32)	('34)
S.A. 250---------	Union Pacific Coal Company, "B" Mine			('34)
S.A. 104---------	Union Pacific Coal Company, Mine "C"			('32)
S.A. 17----------	United States Coal and Coke Company, No. 4 Mine			('29)
S.A. 2-----------	United States Coal and Coke Company, No. 6 Mine			('27)
S.A. 105---------	United States Fuel Company			('32)
S.A. 251---------	United States Fuel Company, King No. 2 Mine			('34)
S.A. 18----------	United States Fuel Company, Panther Mine			('29)

Safety Award No.	Name	Year
S.A. 252	Vesta Coal Company, No. 4 Mine	('34)
S.A. 253	Vesta Coal Company, No. 6 Mine	('34)
S.A. 106	West Kentucky Coal Company	('32)
S.A. 167	Weyanoke Coal and Coke Company, Weyanoke Mine	('33)
S.A. 107-168	Windsor Power House Coal Company, Beech Bottom Mine	('32) ('33)
S.A. 169	Youghiogheny and Ohio Coal Company, Dorothy Mine	('33)
S.A. 108) S.A. 170)	Youngstown Mines Corporation, Dehue Mine	('32) ('33)

Metal Mines and Mining Companies

Safety Award No.	Name		Year
S.A. 171--------	Anaconda Copper Mining Company, Great Falls Departments		('33)
S.A. 172--------	Bennett Mining Company, Bennett Mine		('33)
S.A. 35-173-----	Biwabik Mining Company, Biwabik Mine	('30)	('33)
S.A. 9----------	Bristol Mining Company, Bristol Mine		('28)
S.A. 51---------	Brule Mining Company, Berkshire Mine		('31)
S.A. 174--------	Castile Mining Company, Eureka-Asteroid Mine		('33)
S.A. 109--------	Cleveland Cliffs Iron Company		('32)
S.A. 52-175-----	Cleveland Cliffs Iron Company, Gardner-Mackinaw Mine	('31)	('33)
S.A. 10---------	Cleveland Cliffs Iron Company, Negaunee Mine		('28)
S.A. 53-176-----	Cleveland Cliffs Iron Company, Tilden Mine	('31)	('33)
S.A. 254--------	Copper Range Company, Champion Mine.		('34)
S.A. 110--------	Copper Range Company, Champion No. 1 Shaft		('32)
S.A. 11-177-----	Crete Mining Company, Albany Mine...	('28)	('33)
S.A. 178--------	Cuyuna Ore Company, Mahnomen Mine ..		('33)
S.A. 255--------	Empire Star Mines Company, Limited, Empire Mine, Underground Department		('34)
S.A. 19---------	Federal Mining & Smelting Company, Lucky Bill Mine		('29)
S.A. 3----------	Federal Mining & Smelting Company, Muncie Mine		('27)
S.A. 111--------	Hanna Company, M. A.		('32)
S.A. 179--------	Hanna Iron Ore Company, Hiawatha Mine		('33)
S.A. 36---------	Hanna Ore Mining Company, Harold Mine		('30)
S.A. 112--------	Inland Steel Company, Armour No. 2 Mine		('32)
S.A. 113--------	Inland Steel Company, Greenwood Mine		('32)
S.A. 256--------	James Mining Company, James Mine ...		('34)
S.A. 180--------	Mahoning Ore & Steel Company, Mahoning Mine		('33)
S.A. 114--------	Miami Copper Company		('32)
S.A. 54---------	Mineral Mining Company, Wauseca Mine		('31)
S.A. 55---------	Montreal Mining Company, Montreal No. 4 Shaft		('31)
S.A. 115-181-257	Montreal Mining Company, No. 5 Shaft, Underground Department	('32)('33)	('34)

Safety Award No.	Name			Year
S.A. 182	Montreal Mining Company, No. 6 Shaft, Underground Department			('33)
S.A. 20	Orwell Iron Company, Dunwoody Mine			('29)
S.A. 21	Penn Iron Mining Company, East Vulcan Mine			('29)
S.A. 37	Phelps Dodge Corporation and Old Dominion Company			('30)
S.A. 56-116	Pickands, Mather and Company		('31)	('32)
S.A. 57	Pickands, Mather and Company, West Vulcan Mine			('31)
S.A. 183	Plymouth Mining Company, Plymouth Mine			('33)
S.A. 117	Republic Steel Corporation, Northern Ore Mines			('32)
S.A. 38	Richmond Iron Company			('30)
S.A. 184	Richmond Iron Company, Richmond Mine			('33)
S.A. 185	Sagamore Ore Mining Company, Sagamore Mine			('33)
S.A. 258	Tennessee Coal, Iron and Railroad Company, Ore Mining Division			('34)
S.A. 58-186-259	Tennessee Copper Company	('31)	('33)	('34)
S.A. 187-260	Townsite Mining Company, Townsite Mine		('33)	('34)
S.A. 261	Utah Copper Company, Magna Plant ...			('34)
S.A. 118	Utah Copper Company, Open Cut Mine..			('32)
S.A. 119	Vinegar Hill Zinc Company			('32)
S.A. 59-188	Wakefield Iron Company, Wakefield Mine		('31)	('33)
S.A. 189-262	Youngstown Mines Corporation, Newport Mine		('33)	('34)

Nonmetallic Mines or Plants

Safety Award No.	Name			Year
S.A. 190-------	Alpha Portland Cement Company, Ironton Mine			('33)
S.A. 60--------	Alpha Portland Cement Company, Ironton Plant			('31)
S.A. 61--------	Alpha Portland Cement Company, Manheim Plant			('31)
S.A. 191-------	Avery Salt Company, Avery Plant ...			('33)
S.A. 192-------	Certain-teed Products Corporation .			('33)
S.A. 12-22-62--	Cowell Portland Cement Company	('28)	('29)	('31)
S.A. 39-120----	Lehigh Portland Cement Company		('30)	('32)
S.A. 263-------	Lehigh Portland Cement Company, Birmingham Plant			('34)
S.A. 63-264----	Lehigh Portland Cement Company, Iola Plant		('31)	('34)
S.A. 265-------	Lehigh Portland Cement Company, Ormrod No. 2 Plant			('34)
S.A. 266-------	Lehigh Portland Cement Company, Ormrod No. 3 Plant			('34)
S.A. 64-267----	Medusa Portland Cement Company		('31)	('34)
S.A. 65--------	North American Cement Corporation, Berkeley Lime Plant			('31)
S.A. 268-------	Potash Company of America, No. 1 Shaft			('34)
S.A. 193-------	United States Gypsum Company, Plasterco, Va.			('33)
S.A. 13--------	United States Gypsum Company, Genoa Plant			('28)
S.A. 66--------	Universal Atlas Cement Company, Universal Plant			('31)

Petroleum Plants or Companies

S.A. 67--------	Comar Oil Company, Tonkawa Production District		('31)
S.A. 121-------	Mexican Petroleum Corporation of Louisiana, Oil Refinery		('32)
S.A. 68-122----	Midwest Refining Company, Salt Creek Field	('31)	('32)
S.A. 194-------	Ohio Oil Company, Illinois Producing Division		('33)
S.A. 123-------	Shell Petroleum Corporation		('32)
S.A. 195-------	Standard Oil of Louisiana		('33)
S.A. 69--------	Standard Oil of Louisiana, Baton Rouge Refinery		('31)

Quarries

Safety Award No.	Name			Year
S.A. 71	Cowell Portland Cement Company, Cowell Quarry			('31)
S.A. 269	Inland Lime and Stone Company, Limestone Quarry, Crushing and Screening Plant			('34)
S.A. 4-71	Louisville Cement Company, Speed Quarry		('27)	('31)
S.A. 72	Pennsylvania-Dixie Cement Corporation, No. 4 Quarry			('31)

Associations

Safety Award No.	Name			Year
S.A. 73	Alabama Mining Institute			('31)
S.A. 40-124-270	Portland Cement Association	('30)	('32)	('34)
S.A. 74	Tri-State Zinc and Lead Ore Producers Association			('31)

Mills or Smelters

Safety Award No.	Name			Year
S.A. 271	Ducktown Chemical and Iron Company			('34)
S.A. 125	Eagle-Picher Lead Company, Hillsboro Illinois Plant			('32)
S.A. 41	Phelps Dodge Corporation, Morenci Branch, Clifton Smelter			('30)

Miscellaneous

Safety Award No.	Name			Year
S.A. 126	Baker Company, John E.			('32)
S.A. 272	Columbia Steel Company, Ironton Plant			('34)
S.A. 273	Hetch Hetchy Water Supply Shaft Sinking and Tunneling, Coast Range Division			('34)

Individuals

Safety Award No.	Name			Year
S.A. 127-196-274	Alexander, Alexander A.	('32)	('33)	('34)
S.A. 197--------	Anderson, Matthew H.			('33)
S.A. 128--------	Axon, William			('32)
S.A. 129--------	Ayer, Frank			('32)
S.A. 275--------	Baily, John W.			('34)
S.A. 198--------	Butler, James Pierce			('33)
S.A. 199--------	Chadwick, Joseph Duke Mellor, Sr..			('33)
S.A. 200--------	Conezny, Charles			('33)
S.A. 276--------	Estes, Brownlow			('34)
S.A. 130--------	Fox, William Harvey			('32)
S.A. 201--------	Goulder, Edmund			('33)
S.A. 75---------	Hillhouse, William B.			('31)
S.A. 202--------	Holupka, Michael			('33)
S.A. 131--------	Hovanec, George J.			('32)
S.A. 203--------	Hudson, Eph			('33)
S.A. 76---------	Hughes, William			('31)
S.A. 132--------	John, Jonathan Blaine			('32)
S.A. 277--------	Knight, Harry G.			('34)
S.A. 77---------	Kulaszewicz, Dominick			('31)
S.A. 204--------	Lichtenfeld, Henry C.			('33)
S.A. 205--------	Light, Wes			('33)
S.A. 78---------	Mattson, Chris			('31)
S.A. 133--------	McCaa, Robert D.			('32)
S.A. 206--------	McNamara, Michael			('33)
S.A. 79---------	Meagher, Richard D.			('31)
S.A. 23---------	Middleton, F. E.			('29)
S.A. 207--------	Moffat, Alexander			('33)
S.A. 278--------	Morgan, David			('34)
S.A. 134--------	Morgan, John Philip			('32)
S.A. 279--------	Moyes, David			('34)
S.A. 24---------	Muir, David H.			('29)
S.A. 135--------	Murphy, Patrick			('32)
S.A. 208--------	Peterson, Joseph			('33)
S.A. 280--------	Reninger, Henry A.			('34)
S.A. 209--------	Sloan, Robert, Sr.			('33)
S.A. 136--------	Smith, Frank J.			('32)
S.A. 210--------	Smithers, John Wesley			('33)
S.A. 211--------	Smitley, Lewis C.			('33)
S.A. 212-281----	Thomas, Daniel		('33)	('34)
S.A. 42---------	Thurmond, W. B.			('30)
S.A. 282--------	Underwood, Elgie			('34)
S.A. 213--------	Whalen, Thomas			('33)
S.A. 80---------	Washington, Thomas			('31)
S.A. 283--------	Wilkerson, William			('34)
S.A. 137--------	Wilson, Thomas Rolon			('32)

SAFETY AWARDS, BY YEARS

1927

Coal Mine and Mining Companies

S.A. 1

FORD COLLIERIES COMPANY
Curtisville, Pennsylvania

for having worked 922,628 underground man-shifts, from August 14, 1920, to December 31, 1926, producing 5,755,669 short tons of coal without an underground fatality.

S.A. 2

NO. 6 MINE
UNITED STATES COAL AND COKE COMPANY
Gary, West Virginia

for having worked 606,072 underground man-shifts and 214,667 surface man-shifts from February 24, 1917, to December 31, 1926, producing 6,030,862 short tons of coal without a fatality.

Metal Mine

S.A. 3

MUNCIE MINE
FEDERAL MINING AND SMELTING COMPANY
Baxter Springs, Kansas

for having worked 39,489 underground man-shifts from July 23, 1925, to December 31, 1926, without a lost-time underground accident.

Quarry

S.A. 4

SPEED OPEN LIMESTONE-ROCK QUARRY
LOUISVILLE CEMENT COMPANY
Speed, Indiana

for having worked 60,611 man-shifts from June 1, 1924, to December 31, 1926, without a lost-time accident.

1928

Coal Mines and Mining Companies

S.A. 5

SPRINGDALE MINE
ALLEGHENY PITTSBURGH COAL COMPANY
Logans Ferry, Pennsylvania

for having worked without a fatal accident from May 5, 1923, to October 28, 1927, with 350 as average number of men employed and total tonnage 2,039,152. From July 7, 1924, to January 8, 1925, while producing normally, there was not a single lost-time accident.

S.A. 6

ROBINSON NO. 1 MINE
COLORADO FUEL AND IRON COMPANY
Walsenburg, Colorado

for having operated without a fatal accident from July 27, 1915, to March 1, 1928, or more than 12½ years, the coal production during the period being 2,301,804 tons.

S.A. 7

NO. 6 MINE
PHELPS DODGE CORPORATION
Dawson, New Mexico

for its effective method of training of new or inexperienced employees who worked a representative section of the mine for 20 months and produced 45,000 tons of coal with three minor accidents totaling 10 lost days.

S.A. 8

STEWART MINE
W. J. RAINEY, INC.
Southwest, Pennsylvania

for having operated without a fatality or an accident entailing permanent or partial disability from January 1, 1921, to February 20, 1928. From January 1, 1921, to December 31, 1927, an average force of 266 men were employed, production being 2,991,831 tons and hours of exposure 3,825,680.

Metal Mines and Mining Companies

S.A. 9

BRISTOL MINE
THE BRISTOL MINING COMPANY
Crystal Falls, Michigan

for having operated without a lost-time accident from May 12, 1926, to February 5, 1928, there being 743,780 man-hours of exposure and 632,946 tons of ore produced.

S.A. 10

NEGAUNEE MINE
CLEVELAND CLIFFS IRON COMPANY
Ishpeming, Michigan

for having operated without a fatal accident from January 23, 1919, to March 1, 1928, with 664,820½ shifts worked and 3,580,251 tons mined.

S.A. 11

OPEN PIT ALBANY MINE
CRETE MINING COMPANY
Hibbing, Minnesota

for having operated without a lost-time accident from February 16, 1923, to February 16, 1928, during which period 1,311,000 tons of material were moved.

Nonmetallic Mines and Plants

S.A. 12 COWELL OPERATION
COWELL PORTLAND CEMENT COMPANY
Cowell, California
for having worked 1,081,250 man-hours, from May 11, 1926 to November 26, 1927, without a lost-time accident.

S.A. 13 GENOA PLANT
UNITED STATES GYPSUM COMPANY
Genoa, Ohio
for having operated without a fatality or a lost-time accident from May 12, 1925 to September 2, 1927, with an average of 226 employees involving 1,383,084 man-hours of exposure.

1929

Coal Mines and Mining Companies

S.A. 14 JOHNSTOWN DIVISION
BETHLEHEM MINES CORPORATION
Johnstown, Pennsylvania
for having worked six mines with 1,700 employees for 3,231,723 man-hours in 1928, producing 2,132,562 tons of coal with but 1 fatality and 54 lost-time accidents. From 1924 to 1928 inclusive this division produced 1,167,108 tons of coal per fatality.

S.A. 15 NO. 12 MINE
MADISON COAL CORPORATION
Dewmaine, Illinois
for having worked an average of 760 men from September 29, 1925 to January 20, 1929, producing 2,211,393 tons of coal without a fatality. An average of 633 men worked through a seven-year period producing 802,434 tons of coal per fatality.

S.A. 16 O'GARA COAL COMPANY
Harrisburg, Ill.
for having operated nine mines throughout the entire year 1928, employing 2,300 persons and producing 1,313,206 tons of coal without a fatal accident.

S.A. 17

NO. 4 MINE
UNITED STATES COAL & COKE COMPANY
Thorpe, West Virginia

for having worked an average of 257 men a total of 1,279,328 man-hours during a three-year period without a fatality and with accident-frequency rate 11.724 and accident-severity rate 0.342.

S.A. 18

PANTHER MINE
UNITED STATES FUEL COMPANY
Heiner, Utah

for having worked an average of 87 men a total of 376,324 man-hours during the past three calendar years without a fatality and with 31 lost-time accidents totaling 564 days giving severity rate of 1.499.

Metal Mines and Mining Companies

S.A. 19

LUCKY BILL MINE
FEDERAL MINING & SMELTING COMPANY
Cardin, Oklahoma

for having operated 378,694 man-hours during the last three years without a fatality and with but four lost-time accidents totaling 690 lost days giving frequency rate of 10.563.

S.A. 20

DUNWOODY MINE
ORWELL IRON CO.
Chisholm, Minn.

for having operated an open pit and underground iron ore mine, employing an average of 150 employees, a total of 1,212,386 man-hours, producing 2,347,737 tons of ore during the past three years without a fatality and with but three lost-time accidents totaling 99 days.

S.A. 21

EAST VULCAN MINE
PENN IRON MINING COMPANY
Vulcan, Michigan

for having worked an average of 199 men a total of 925,000 man-hours, from January 26, 1927, to January 26, 1929, producing 424,109 tons of material from an underground iron ore mine with no lost-time accidents.

Nonmetallic Mines and Plants

S.A. 22 COWELL PORTLAND CEMENT COMPANY
Cowell, California
for having worked its entire plant, involving about 208 men, from May 11, 1926, to February 25, 1929, a total of 1,758,065½ man-hours, without a lost-time accident, producing 1,749,176 barrels of cement. The quarry worked a total of 415,354½ man-hours from August 14, 1925 to February 25, 1929, without a lost-time accident.

Individuals

S.A. 23 F. E. MIDDLETON
SUPERINTENDENT OF STEWART AND PERRYOPOLIS MINE
W. J. RAINEY, INC.
Southwest, Pennsylvania
for having acted from 1905 to 1919, as coal-mine foreman, and from 1919 to 1929, as superintendent. During the entire 24 years only one fatal accident occurred to the 200 or more men under Mr. Middleton's direct jurisdiction.

S.A. 24 DAVID H. MUIR
Walsenburg, Colo.
for having acted as mine foreman at the Robinson No. 1 Mine of the Colorado Fuel & Iron Company, Walsenburg, Colorado, from July 27, 1915 to February 21, 1929, a total of 13 years, 6 months, and 24 days, the production being 2,475,555 tons of coal, without having a fatal accident in the mine.

1930

Coal Mines and Mining Companies

S.A. 25 WEST VIRGINIA DIVISION
CONSOLIDATION COAL COMPANY
Fairmont, West Va.
for having produced 1,358,586 tons of coal per fatality in 1929, against approximately 343,000 tons per fatality in 1926, when a new safety system was inaugurated.

S.A. 26

WESTERN DIVISION
DEBARDELEBEN COAL CORPORATION
Coal Valley, Alabama

for having worked an average force of 893 from February 3, 1928, to February 3, 1930, a total of 2,553,835 man-hours, without a fatality or a permanent total disability and with but one permanent partial disability.

S.A. 27

NEWCASTLE NO. 2 and NO. 6 MINES
NEWCASTLE COAL COMPANY
Newcastle, Alabama

for having worked from November, 1919, to January 1, 1930, or more than 10 years with but one fatality and with a coal tonnage of 3,170,358. During 1929 an average force of 335 was employed.

S.A. 28

ODIN MINE
ODIN COAL COMPANY
Odin, Illinois

for having operated from September 14, 1907, to January 1, 1930, inclusive, or over 22 years without a fatal accident, producing 4,095,087 tons of coal with 8,120,284 man-hours exposure.

S.A. 29

PHELPS DODGE CORPORATION
STAG CANON BRANCH

for having reduced the number of lost-time accidents per 1,000 shifts worked at its coal mines from 1.656 in 1924 to 0.133 in 1929.

S.A. 30

ADRIAN MINE
ROCHESTER AND PITTSBURGH COAL COMPANY
Indiana, Pennsylvania

for having worked chiefly in pillar coal from January 31, 1924, to January 6, 1930, producing 2,153,195 tons of coal without a fatality; a fatality occurred in 1927 in the adjacent Florence mine while some of its coal was being taken through the Adrian Mine.

S.A. 31

SHAMROCK MINE
SHAMROCK COAL COMPANY
Frederick, Colorado

for having operated from 1904 to 1929, inclusive, without a fatality or without serious injuries. The production from 1913 to 1929 was 870,152 tons, exposure being 961,232 man-hours and average force 38.

S.A. 32 SHERIDAN WYOMING COAL COMPANY
Sheridan, Wyoming

for having operated its three mines from 1925 to 1929, inclusive, with an average of 446 men, producing 4,116,998 tons of coal with but 27 lost-time compensable accidents and without a fatality or a permanent total disability and with but one permanent partial disability.

S.A. 33 ELIZABETH MINE
W. B. SKELLY COAL CO.
Export, Pa.

for having operated (with minimum annual tonnage 5,000 in 1900) from 1900 to date (February 1, 1930) without a fatal accident, coal production being somewhat over 2,100,000 tons.

S.A. 34 SUPERIOR COAL COMPANY
Gillespie, Illinois

for the excellent safety record of having produced 1,161,415 tons of coal per fatality during the past seven years. In 1927 its entire four mines produced 2,005,040 tons of coal without a fatality or a total disability.

Metal Mines and Mining Companies

S.A. 35 BIWABIK MINE
BIWABIK MINING COMPANY
Biwabik, Minnesota

for having operated an open-pit iron ore property from June, 1926 to November, 1929, or 42 months, without a lost-time accident. Average number employed was 31.5 for five months each year and 85 for seven months.

HAROLD MINE
S.A. 36 HANNA ORE MINING COMPANY
Hibbing, Minnesota

for having worked an average force of 123 from May 26, 1928, to January 1, 1930, a total of 471,283 man-hours, producing 449,764 tons of ore with but one lost-time accident, this causing 47 days lost time. From May 26, 1928, to October 10, 1929, or about 16½ months, the mine operated without a lost-time accident.

S.A. 37

PHELPS DODGE CORPORATION
AND OLD DOMINION COMPANY

for having reduced the number of lost-time accidents per 1,000 shifts worked at the metal-mining properties of these companies from 1.047 in 1924 to 0.038 in 1929.

S.A. 38

RICHMOND IRON COMPANY
Palmer, Michigan

for having operated its Richmond open-pit iron ore property through 1928 and 1929 with an average force of 35, for 130,719 man-hours, without a lost-time accident; 318,059 tons of ore were produced and 80,276 cubic yards of stripping handled.

Nonmetallic Mines and Plants

S.A. 39

LEHIGH PORTLAND CEMENT COMPANY

for its exceptionally good safety work and record. From 1924 to 1929, inclusive, except in 1925, one or more of its cement plants won the Portland Cement Association trophy for working without a lost-time accident through the calendar year. Five plants won this trophy in 1928 and four in 1929. The Iola, Kansas, plant involving over 200 employees has not had a lost-time accident for nearly $3\frac{1}{2}$ years and the Ormrod, Pa., plant has been free of lost-time accidents for over two years.

Associations

S.A. 40

PORTLAND CEMENT ASSOCIATION

for an outstanding safety record in connection with its trophy contest in which entire cement plants operated a full calendar year without a lost-time accident as follows: 1 plant out of 105 in 1924; 2 out of 118 in 1928; 2 out of 124 in 1926; 10 out of 136 in 1927; and 17 out of 136 in 1928. In 1929, 28 out of 150 or nearly one in every five worked through the year without a single lost-time accident.

Smelter

PHELPS DODGE CORPORATION
MORENCI BRANCH
CLIFTON SMELTER

S.A. 41 for having operated an average force of 186 from June 5, 1927, to October 23, 1929 (2 years and 136 days), a total of 1,171,784 man-hours, without a lost-time accident.

Individuals

S.A. 42 W. B. THURMOND
UNITED STATES SMELTING REFINING
AND MINING COMPANY
for having operated the main hoist of the Centennial Eureka Mine, Eureka, Utah, from 1892 to 1925, a span of 33 years, without having injured any one in the hoisting operations.

1931

Coal Mines and Mining Companies

S.A. 43 NELLIS MINE
THE AMERICAN ROLLING MILL COMPANY
Nellis, West Virginia
for having decreased its accident frequency rate from 89.9 in 1926 to 12.65 in 1930, and severity rate from 10.81 in 1926 to 0.91 in 1930, production being over 300,000 tons and exposure over 550,000 man-hours annually. The mine had 162 consecutive days without a lost-time accident and had 7 "no-accident" calendar months in 1930.

S.A. 44 NO. 2 MINE
BELL AND ZOLLER COAL AND MINING COMPANY
Zeigler, Illinois.
for having worked an average force of 1,000 men from August 6, 1928, through December 31, 1930, a total of 3,818,760 man-hours, producing 3,115,687 tons of coal without a fatality, having had 697 injuries totaling 7,269 days lost time.

S.A. 45 THE ELKHORN DIVISION
THE CONSOLIDATION COAL COMPANY
Jenkins, Kentucky
for having produced approximately 2,860,000 tons of coal in 1930 with but two fatalities, this being but 0.816 fatality per million tons as compared with 3.410 for all bituminous mines of the United States.

S.A. 46 HULL MINE
DEBARDELEBEN COAL CORPORATION
Dora, Alabama
for having worked during 1930, 11 months and 20 days, a total of 301,763 man-hours, producing 100,699 tons of coal, without a lost-time accident.

S.A. 47

NO. 19 MINE
PEABODY COAL COMPANY
West Frankfort, Illinois

for having worked an average of 541 men a total of 4,804,308 man-hours, from 1925 to 1939, inclusive, producing 3,276,223 tons of coal, without a fatality.

S.A. 48

MATHER MINE
PICKANDS, MATHER & COMPANY
Mather, Pa.

for having worked an average of 782 men a total of 1,676,608 man-hours, producing 1,043,185 tons of coal during 1930 without a fatality or a permanent disability and with but 52 lost-time compensable accidents.

S.A. 49

SAGAMORE MINE
POCAHONTAS FUEL COMPANY
McComas, West Virginia

for having worked from November 18, 1922, through December 31, 1930, or 8 years, 1 month, and 13 days, producing 2,423,570 tons of coal without a fatality.

S.A. 50

STEWART MINE
W. J. RAINEY, INC.
Southwest, Pa.

for having operated from its opening in 1921 to its abandonment in 1930, or nine years, working approximately 5,000,000 man-hours and producing over 4,000,000 tons of coal, without a fatality or a permanent disability and with but one permanent partial disability, and without a fire or an explosion though the mine was gassy.

Metal Mines and Mining Companies

S.A. 51

BERKSHIRE MINE
BRULE MINING COMPANY
Stambaugh, Michigan

for having operated from December 10, 1927, to December 10, 1930, or 3 years, working 1,044,768 man-hours, and producing 721,594 tons of ore, without a lost-time accident.

S.A. 52

GARDNER-MACKINAW MINE
THE CLEVELAND-CLIFFS IRON COMPANY
Gwinn, Michigan

for having operated during 1929 without a lost-time accident, producing 117,224 tons of semihard iron ore, working 32,029 man-shifts; for having but one lost-time accident in 1930, producing 125,157 tons, working 33,181 man-shifts; and for having 545 days of continuous operation without a lost-time accident.

S.A. 53

TILDEN MINE
CLEVELAND-CLIFFS IRON COMPANY
Ishpeming, Michigan

for having operated an open-pit iron mine during 1930, working 13,091 man-shifts, and producing 287,043 tons of ore, without a lost-time accident.

S.A. 54

WAUSECA MINE
MINERAL MINING COMPANY
Iron River, Michigan

for having operated an underground iron ore mine from 1910 to 1930, inclusive, without a fatality or a permanent partial disability; during 1928, 1929, and 1930, an average of 50 persons worked 42,621 shifts, producing 142,995 tons with but 9 accidents totaling 42 days lost time.

S.A. 55

MONTREAL NO. 4 SHAFT
MONTREAL MINING COMPANY
Montreal, Wisconsin

for having operated an underground iron mine for 477 calendar days with 623,520 man-hours, from September 11, 1929, to January 1, 1931, without a lost-time accident.

S.A. 56

PICKANDS, MATHER AND COMPANY

for having operated 28 mines in the Lake Superior region the entire month of November, 1930, employing an average of 2,942.9 men, a total of 62,817.96 man-days, or 570,400 man-hours, about two-thirds in underground mines, producing 1,045,715 tons of ore, rock, waste, and stripping, without the loss of a single day to any employee due to injury.

S.A. 57

WEST VULCAN MINE
PICKANDS, MATHER AND COMPANY
Vulcan, Michigan

for having worked an average of 123 men in an underground iron ore mine from December 1, 1929, to December 31, 1930, inclusive, a total of 37,777 man-days, producing 136,577 tons of ore, without the loss of a single day to any employee due to injury.

S.A. 58

TENNESSEE COPPER COMPANY
Copperhill, Tennessee

for having reduced the number of accidents from 413 in 1923, with 2,192,936 man-hours of exposure to 15 in 1930, with 2,757,114 man-hours, the frequency rate being reduced from 188.33 in 1923 to 5.44 in 1930, or a reduction of 97.11 percent.

S.A. 59

WAKEFIELD MINE
WAKEFIELD IRON COMPANY
Wakefield, Michigan

for having operated a combined open pit and underground iron mine for 18 months, ending December 31, 1930, a total of 538,049 man-hours, without a lost-time accident.

Nonmetallic Mines and Plants

S.A. 60

IRONTON PLANT
ALPHA PORTLAND CEMENT COMPANY
Ironton, Ohio

for having operated from December 8, 1926, through December 31, 1930, a total of 1,484 days, or more than 4 years, without a lost-time accident.

S.A. 61

MANHEIM PLANT
ALPHA PORTLAND CEMENT COMPANY
Manheim, West Virginia

for having operated the entire cement plant, with an average of 150 men, during 1928, 1929, and 1930, without a fatality and with but one lost-time accident; and for employing 50 to 60 men in an underground stone mine without a fatality since November, 1920, and without a lost-time accident since February, 1927.

S.A. 62

COWELL PORTLAND CEMENT COMPANY
Cowell, California

for having worked its entire plant from May 11, 1926, to November 21, 1930, inclusive, a total of 1,653 days or over 4½ years, without a lost-time accident.

S.A. 63

IOLA PLANT
LEHIGH PORTLAND CEMENT COMPANY
Iola, Kansas

for having operated 1,574 days from September 9, 1926, to December 30, 1930, inclusive, working 1,957,626 man-hours, without a lost-time accident. This plant at present holds the outstanding record of the Portland Cement Association for continuous operation without a lost-time accident.

S.A. 64

MEDUSA PORTLAND CEMENT COMPANY
Cleveland, Ohio

for having operated without a lost-time accident seven out of eight plants entered in the Portland Cement Association Trophy Competition in 1930.

S.A. 65

BERKELEY LIME PLANT
NORTH AMERICAN CEMENT CORPORATION
Martinsburg, West Virginia

for operating 8 consecutive years without a fatality, and for working an average of 130 men 568 days without a lost-time accident.

S.A. 66

UNIVERSAL PLANT
UNIVERSAL ATLAS CEMENT COMPANY
Universal, Pa.

for working over 500 men for 484 days, to December 31, 1930, working 1,731,022 man-hours, without a lost-time accident.

Petroleum Plants and Companies

S.A. 67

TONKAWA PRODUCTION DISTRICT
COMAR OIL COMPANY, OKLAHOMA

for working an average of 200 employees a total of 1,413,229 man-hours, from November 24, 1928, to August 26, 1930 (21 months), without a lost-time accident.

S.A. 68

SALT CREEK FIELD
THE MIDWEST REFINING COMPANY
for its effective work in accident prevention, the number of lost-time accidents being reduced from 475 in 1926 to 9 in 1930, and the frequency rate from 87.9 in 1926 to 3.3 in 1930.

S.A. 69

BATON ROUGE REFINERY
STANDARD OIL COMPANY OF LOUISIANA
Baton Rouge, Louisiana
for operating daily (except Sundays) during 1930, working an average of 4,556 men a total of 12,268,656 hours, without a fatality and with but 73 lost-time accidents totaling 1,128 lost days.

Quarries

S.A. 70

COWELL QUARRY
COWELL PORTLAND CEMENT COMPANY
Cowell, Calif.
for having worked an average of 30 employees from August 14, 1925, to November 21, 1930, inclusive, a total of 569,739-1/2 man-hours or more than 5 years, without a lost-time accident.

S.A. 71

SPEED QUARRY
LOUISVILLE CEMENT COMPANY
Speed, Indiana
for having worked an average of 85 employees from May 31, 1924, to October 13, 1930, or 6 years, 4 months, and 12 days, with a total of 1,159,206 man-hours, without a lost-time accident.

S.A. 72

NO. 4 QUARRY
PENNSYLVANIA-DIXIE CEMENT CORPORATION
Nazareth, Pennsylvania
for having worked an average of 31 men a total of 370,659 man-hours, from November 1, 1925, to January 31, 1931, inclusive, or more than 5 years without a lost-time accident.

Associations

S.A. 73 ALABAMA MINING INSTITUTE

for its effective work in coordinating the accident-prevention efforts of various mining organizations of Alabama with resultant material reduction in the accident rate of the coal mines of that State.

S.A. 74 TRI-STATE ZINC AND LEAD ORE PRODUCERS ASSOCIATION

for its effective work in health and safety in the lead-zinc mines in the Tri-State region.

Individuals

S.A. 75 WILLIAM B. HILLHOUSE

CHIEF OF THE DEPARTMENT OF MINES OF ALABAMA

for having so directed or cooperated with various coal-mining agencies in Alabama as to bring about a reduction in fatalities from 139 in 1926 to 61 in 1930, with corresponding decrease in the fatality rate per million man-hours of exposure and per million tons of coal mined.

S.A. 76 WILLIAM HUGHES

for having worked more than 57 years in coal mines, from November, 1872, to January, 1930, without having had a lost-time injury or having caused one to any other person.

S.A. 77 DOMINICK KULASZEWICZ

for having worked at the Biwabik Mine, Biwabik, Minnesota, from 1893 to the present, without a disabling accident, being employed as locomotive fireman, brakeman, and locomotive engineer.

S.A. 78 CHRIS MATTSON

for having had charge of the sinking of seven shafts with total depth of 1,182 feet, from July, 1921, to November, 1929, during which time no disability accidents occurred on any of the work.

S.A. 79 RICHARD D. MEAGHER

for having worked more than 43 years in coal mines, from September, 1883, to January, 1927, and for having acted in a supervisory capacity as foreman and superintendent for 30 years, without having had a fatality to the approximately 300 men under his supervision.

S.A. 80 THOMAS WASHINGTON

for having handled explosives in blasting in the quarries of the Standard Lime & Stone Company, Martinsburg, W. Va., for 37 years without an accident.

1932

Coal Mines and Mining Companies

S.A. 81 NO. 71 MINE
BETHLEHEM MINES CORPORATION
Johnstown, Pa.

for having operated without a fatality from November 22, 1927, to September 19, 1931, or more than 3 years and 9 months, employing an average of 450 men working 2,719,365 man-hours and producing 1,931,569 tons of coal.

S.A. 82 BIRD COAL COMPANY
Tire Hill, Pa.

for having worked without a fatality from March 1, 1928, to December 31, 1931, with approximately 3,250,120 man-hours of exposure, producing 1,730,478 tons of coal.

S.A. 83 BRIER HILL MINE
THE BUCKEYE COAL COMPANY
Brier Hill, Pa.

for working from December 10, 1930, to December 11, 1931, without a fatality or a disability exceeding the remainder of the day of the injury, with production of 184,306 tons of coal by an average of 257 men employed for a total of 343,363 man-hours.

S.A. 84 SOMERSET MINE
CALUMET FUEL COMPANY
Somerset, Colorado

for operating without a fatality from March 20, 1923, through December 31, 1931, or over 8-3/4 years, working more than 2,500,000 man-hours and producing about 1,750,000 tons of coal from a gassy, inclined, thick coal bed under exceptionally heavy cover.

S.A. 85

DEBARDELEBEN COAL CORPORATION
Birmingham, Alabama

for operating 7 coal mines without a fatality in 1931, producing 782,394 tons of coal and working 2,292,857 man-hours. Twenty-seven bosses had no compensable accidents in their respective sections through the entire year.

S.A. 86

EBENSBURG NO. 1 MINE
EBENSBURG COAL COMPANY
Colver, Pa.

for working an average of 750 men without a fatality from November 23, 1929, through December 31, 1931, producing 1,871,862 tons of coal in 363,750 man-days.

S.A. 87

ALLOY MINE
ELECTRO-METALLURGICAL COMPANY
Alloy, W. Va.

for operating without a fatality or lost-time accident for one year, handling 222,151.61 net tons of material, including 129,153.61 net tons of bituminous coal, with an average of 140 employees working 343,778 man-hours.

S.A. 88

MINE 58
ELLSWORTH COLLIERIES COMPANY
Marianna, Pa.

for operating without a fatality from November 21, 1929, to March 1, 1932, with an average of 709 employees working 2,553,675 man-hours and producing 1,414,365 tons of coal.

S.A. 89

EMPIRE "A" MINE
EMPIRE COAL MINING COMPANY
Barnesboro, Pa.

for producing 533,820 tons of coal entirely in pillar extraction, working 149,961 man-days from October 31, 1924, through 1931, without a fatality.

S.A. 90

HOTCHKISS MINE
HOTCHKISS COAL COMPANY
Dietz, Wyoming

for working from April, 1920, to December 31, 1931, or over 11 years, without a fatality, producing 672,107 tons of coal; and for producing 30,826 tons in 1931 with but one compensable accident.

S.A. 91

LIBERTY MINE
LIBERTY FUEL COMPANY
Latuda, Utah

for having worked from December 8, 1925, to December 8, 1930, or 5 years, without a fatality, producing 1,018,000 tons of coal, with an average of 102 employees, working a total of 1,097,016 man-hours.

S.A. 92

CARBONADO MINE
PACIFIC COAST COAL COMPANY
Carbonado, Washington

for operating in 1931 with no fatalities and but 21 lost-time accidents, producing 139,995 tons of coal with 374,704 man-hours of exposure, and for working 3 full months in steeply pitching workings in thick coal without a lost-time accident. This mine has reduced lost-time accidents from 102 in 1928 to 70 in 1929, 95 in 1930, and 21 in 1931.

S.A. 93

PENELEC COAL CORPORATION
Seward, Pa.

for working without a fatality for 4 years from 1928 to 1931, inclusive, employing an average of 203 men and producing 742,669 tons of coal. Average accident frequency was 86.9 and severity 1.20.

S.A. 94

EHRENFELD NO. 8 MINE
PENNSYLVANIA COAL AND COKE CORPORATION
Ehrenfeld, Pa.

for having operated without a fatality or a permanent total or permanent partial disability to an average of 90 men from September 1, 1922, through December 31, 1931, or over 9 years, producing 1,073,175 tons of coal.

S.A. 95

NO. 17 COLLIERY
PENNSYLVANIA COAL AND COKE CORPORATION
Barnesboro, Pennsylvania

for having operated without a fatality and with but one permanent disability to an average of 209 employees from June 28, 1913, through December 31, 1931, or 18-1/2 years, producing 3,018,789 tons of coal.

S.A. 96

NO. 1 MINE
PHELPS DODGE CORPORATION
Dawson, New Mexico

for working through 1931 without a lost-time accident, producing 68,237 tons of coal in 12,905 man-shifts from a gassy mine with bad roof conditions and largely from extraction of pillars. In 1930 this mine had but 4 lost-time accidents.

S.A. 97

BROOKSIDE COLLIERY
THE PHILADELPHIA & READING COAL & IRON COMPANY
Tower City, Pennsylvania

for working through November and December, 1931, and January, 1932, with but 5 lost-time accidents causing a total of 23 days lost time to a force of approximately 1,000 employees while producing 144,451 tons of anthracite coal. This record was made possible through the excellent cooperation of the officials and an employees' safety committee of over 100 persons.

S.A. 98

SOLDIER NO. 1 MINE
ROCHESTER AND PITTSBURGH COAL COMPANY
Soldier, Pa.

for having worked approximately 13 years without a fatal accident and with few serious accidents, and for having but one compensable accident in 1931 with approximately 100 men employed entirely on pillar extraction.

S.A. 99

ROCKHILL NO. 8 MINE
ROCKHILL COAL & IRON COMPANY
Wood, Pa.

for operating during 1931 with but 4 noncompensable lost-time accidents causing a total loss of 19 days, working an average of 79 men for 142,248 man-hours and producing 65,695 tons of coal, chiefly from pillar work on pitches varying from 10 to 70 per cent.

S.A. 100

MONARCH MINE NO. 45
SHERIDAN-WYOMING COAL CO., INC.
Kleenburn, Wyoming

for operating without a fatality from December 2, 1924, to December 31, 1931, or over 7 years, producing 2,345,001 tons of coal from 1925 to 1931, inclusive; and for producing 257,007 tons in 1931 with but seven compensable injuries.

S.A. 101

SOUTH UNION MINE
SOUTH UNION COAL COMPANY
Uniontown, Pa.

for operating without a fatality from March 10, 1927, through December 31, 1931, producing 2,714,414 tons of coal and working an average of 300 men.

S.A. 102

GALLITZIN MINE
THE TAYLOR AND McCOY COAL & COKE CO.
Gallitzin, Pa.

for operating without a fatality or permanent total disability from June 11, 1917, through December 31, 1931, or over 14-1/2 years, employing an average of 230 men, and producing 1,599,684 tons of coal.

S.A. 103

NO. 4 MINE
THE UNION PACIFIC COAL COMPANY
Rock Springs, Wyoming

for having worked without a fatality from April 17, 1923, through December 31, 1931, or more than 8-1/2 years, employing an average of 216 men for 3,167,712 man-hours and producing 2,476,122 tons of coal.

S.A. 104

MINE C
THE UNION PACIFIC COAL COMPANY
Superior, Wyoming

for operating without a fatality for nearly 4-1/2 years from July 6, 1927, through December 31, 1931, with an average of 133 employees working 1,284,536 man-hours and producing 1,019,753 tons of coal.

S.A. 105

UNITED STATES FUEL COMPANY
Salt Lake City, Utah

for producing over 1,100,000 tons of coal without a fatality from its 3 mines, working largely in extracting pillars. In 1931 more than 546,000 tons were mined by approximately 500 men with no fatalities and but 28 lost-time accidents.

S.A. 106

WEST KENTUCKY COAL COMPANY
Sturgis, Kentucky

for operating its 10 mines in western Kentucky, employing approximately 2,500 men, working 3,457,000 man-hours, from October 29, 1930, to March 1, 1932, producing 2,737,493 tons of coal without a fatality or a permanent total disability. In 1931 this company produced 1,863,663 tons of coal without a fatality.

S.A. 107

BEECH BOTTOM MINE
WINDSOR POWER HOUSE COAL COMPANY
Windsor Heights, W. Va.

for working an average of 450 employees 4 months in 1930 and 9 months in 1931 without a lost-time accident. From December 4, 1930, through March 1, 1932, with 1,049,806 man-hours of exposure, the mine produced 682,800 tons of coal with one fatality and 4 lost-time accidents. There were no lost-time accidents from September 25, 1931, through March 1, 1932.

S.A. 108

DEHUE MINE
THE YOUNGSTOWN MINES CORPORATION
Dehue, West Virginia

for having operated an entire year from January 8, 1931, to January 8, 1932, a total of 378,874 man-hours, producing 261,924 tons of coal and working approximately 375 men without a fatality or loss of as much as a day to any employee from injury.

Metal Mines and Mining Companies

S.A. 109

THE CLEVELAND-CLIFFS IRON COMPANY

for having operated three underground and three open-pit mines more than a year without a lost-time accident, with production of more than 2,600,000 tons of ore and rock. The underground mines were the Morris Lloyd, Cliffs Shaft, and Gardner Mackinaw, in Michigan; the open pits were the Tilden in Michigan and the Holman Cliffs and Hill Trumbull in Minnesota.

S.A. 110

CHAMPION NO. 1 SHAFT
COPPER RANGE COMPANY
Painesdale, Michigan

for working without a lost-time accident from January 2, 1931, to January 2, 1932, handling 140,339 tons of ore and waste, with an average of 100 men, working 27,189 man-shifts.

S.A. 111

M. A. HANNA COMPANY
Duluth, Minnesota

for operating 13 open-pit and underground iron mines (two nonproducing), during 1931 with no fatalities and but 19 compensable and 28 lost-time accidents, with 2,408,599 tons produced in 2,418,631 man-hours exposure. Several of the mines, both open cut and underground, have worked more than a year without the occurrence of a lost-time accident.

S.A. 112

ARMOUR NO. 2 MINE
INLAND STEEL COMPANY
Crosby, Minnesota

for operating an underground iron mine without a fatality from September 19, 1923, to January 11, 1932, or more than 8-1/3 years, working 3,040,900 man-hours and hoisting 2,161,028 tons of ore.

S.A. 113

GREENWOOD MINE
INLAND STEEL COMPANY
Ishpeming, Michigan

for sinking the shaft a depth of 1,031 feet, working 103,024 man-hours with no fatalities and with but 8 accidents causing a total of 95 days lost time.

S.A. 114

MIAMI COPPER COMPANY
Miami, Arizona

for operating its underground mine without a fatality for more than 30 months from July 29, 1929, producing 13,287,517 tons of ore, with an average of 602 men working 4,173,272 man-hours.

S.A. 115

NO. 5 SHAFT, UNDERGROUND DEPARTMENT
THE MONTREAL MINING COMPANY
Montreal, Wisconsin

for working without a fatality or a lost-time accident from May 28, 1930, through December 31, 1931, or 583 days, with 487,224 man-hours exposure and 544,980 tons of iron ore and rock produced from an underground mine.

S.A. 116

PICKANDS, MATHER & COMPANY
Cleveland, Ohio

for operating 28 to 31 iron ore mines in the Lake Superior region with over 3,200 employed and with a remarkable record of mine months without a lost-time accident: 192 out of 360 in 1927, 244 of 360 in 1928, 266 of 372 in 1929, 279 of 339 in 1930, and 275 of 339 in 1931.

S.A. 117 REPUBLIC STEEL CORPORATION,
NORTHERN ORE MINES
Duluth, Minnesota

for operating 4 iron mines in the Lake Superior District in 1931 with but 4 lost-time accidents, the only serious one causing 69 lost days. This company reduced its accident frequency rate from 63.05 in 1930 to 13.9 in 1931, and severity rate from 1.69 in 1930 to 0.28 in 1931.

S.A. 118 OPEN CUT MINE
UTAH COPPER COMPANY
Bingham Canyon, Utah

for reducing its accident rates from a frequency of 121.3 and a severity of 10.1 in 1922 to frequency of 8.6 and severity of 0.2 in 1931. This mine worked the three-year period from January 21, 1929, through January 21, 1932, without a fatality and moved more than 75,000,000 tons of ore and rock, with almost 11,000,000 man-hours exposure to its approximately 1,400 employees.

S.A. 119 VINEGAR HILL ZINC COMPANY
Platteville, Wisconsin

for steadily reducing its accident rate from 1.01 lost-time accidents per 1,000 shifts worked in 1927 to 0.45 in 1931. With 17 accidents causing 327 days lost in 37,736 man-days worked, 1931 gave this company its best accident record in over 20 years in southwest Wisconsin.

Nonmetallic Mines and Plants

S.A. 120 LEHIGH PORTLAND CEMENT COMPANY

for maintenance through 1930 and 1931 of its notable safety record. Seven plants won trophies in 1930 and six plants in 1931 for operating without a lost-time accident. Its Iola, Kansas, plant has operated over 5 years, and its Ormrod No. 2, Pennsylvania, and Birmingham, Alabama, plants over 3 years each without a lost-time accident.

Petroleum Plants and Companies

S.A. 121

OIL REFINERY
MEXICAN PETROLEUM CORPORATION OF LOUISIANA, INC.
Destrehan, La.

for working an average of 206 men 575,390 man-hours, from October 23, 1930, through December 31, 1931, without a fatal or lost-time accident, and but 51 minor injuries. One hundred forty-one employees worked through 1930 and 1931 without any kind of accident.

S.A. 122

SALT CREEK FIELD,
MIDWEST REFINING COMPANY
Casper, Wyoming

for continuing its accident reduction through 1931, having had no fatalities and but 5 lost-time accidents in 2,007,613 man-hours of exposure with its lowest accident frequency rate 2.4 and accident severity rate 0.18; and for working 224 continuous days totaling 1,243,102 man-hours without a lost-time accident.

S.A. 123

SHELL PETROLEUM CORPORATION
St. Louis, Missouri

for operating its properties, employing an average of 10,538 men an average of 28,743,926 man-hours annually, from 1926 to 1931 with a decrease in accident frequency from 51.4 in 1926 to 11.1 in 1931, and in severity from 2.54 in 1926 to 0.47 in 1931. This company had 11,043,411 man-hours of exposure to 4,638 employed in 1926 and 29,202,972 to 10,615 employed in 1931.

Associations

S.A. 124

PORTLAND CEMENT ASSOCIATION

for continuation during 1930 and 1931 of its outstanding safety accomplishments. In 1930, 46 plants out of 128, and in 1931, 42 plants out of 122 operated without a single lost-time accident, 2 plants having worked over 5 years each without a lost-time accident.

Smelter

S.A. 125 HILLSBORO ILLINOIS PLANT
THE EAGLE-PICHER LEAD CO.
for operating without a fatality or a permanent total disability from 1925 through 1931 with 2,534,500 man-hours of work for its average of 124 employees. Frequency rate was 24.8 and severity rate 0.763. There were no lost-time accidents for 983 days through February 17, 1932.

Miscellaneous

S.A. 126 JOHN E. BAKER COMPANY
York, Pa.
for the successful prosecution of a well-planned accident-prevention campaign in its 7 limestone plants, 1 coal mine, and 1 manufacturing plant, with an average of 502 employees. Lost-time accidents were reduced from 307 in 1927 to 16 in 1931 or practically 95 per cent.

Individuals

S.A. 127 ALEXANDER A. ALEXANDER
Nemacolin, Pennsylvania
for acting as assistant foreman in charge of 61 men who worked for 22 months to January, 1932, for 201,732 man-hours, without a lost-time accident.

S.A. 128 WILLIAM AXON
Coral, Pennsylvania
for directing difficult pillar extraction with maximum safety and having worked 55 years in coal mines, largely as foreman or assistant foreman, without having had an injury.

S.A. 129 FRANK AYER
for the outstanding safety records achieved every year during the period 1925 to 1931, inclusive, by mining plants of the Phelps-Dodge Corporation under his management at Nacozari, Sonora, Mexico, and Morenci, Arizona.

S.A. 130

WILLIAM HARVEY FOX
Lawton, West Virginia
for working 15 years in the driving of 9,500 feet of entry with production of 18,554 tons of coal without a lost-time accident, He has worked 50 years in coal mines.

S.A. 131

GEORGE J. HOVANEC
Uniontown, Pennsylvania
for the production of 3,500,843 tons of coal from 1920 through December 31, 1931, without a fatal accident or permanent total disability to employees under his management as mine foreman at the Perry and South Union mines.

S.A. 132

JONATHAN BLAINE JOHN
for his untiring efforts and successful leadership in the safety movement in the cement industry for five consecutive years, and for the excellent safety record made by cement plants under his direct management, eight out of nine having operated through 1930 without a lost-time accident. Every cement plant under his management has worked at least one full calendar year without a lost-time accident.

S.A. 133

ROBERT D. McCAA
for his record of 63 years of continuous employment in or around anthracite mines in Pennsylvania without sustaining a lost-time disabling injury; for 51 years he acted as hoisting engineer without an injury or fatality to persons being hoisted or lowered while he was operating the hoisting engine.

S.A. 134

JOHN PHILIP MORGAN
Bradley, Ohio
for having worked 54 years in coal mines without the loss of a day due to injury.

S.A. 135

PATRICK MURPHY
Brownsville, Pennsylvania
for working in coal mines for 54 years without incurring a lost-time accident.

S.A. 136 FRANK J. SMITH
for the excellent safety accomplishments of mines under his supervision, including the Bristol Mine, Crystal Falls, Michigan, and the Berkeshire Mine, Stambaugh, Michigan, which have both won two or more national safety certificates or trophies for outstanding safety records.

S.A. 137 THOMAS ROLON WILSON
Blairsville, Pa.
for having worked in coal mines for 57 years until retirement in 1930, without a personal injury. From 1898 to 1930 the River Mine under his foremanship produced over 3,000,000 tons of coal with notable care for the safety of the employees.

1933

Coal Mines and Mining Companies

S.A. 138 CRANE CREEK MINE
THE AMERICAN COAL COMPANY OF ALLEGANY COUNTY
McComas, West Virginia
for operating without a fatality from September 7, 1931, to December 31, 1932, employing an average of 511 men for 1,259,104 man-hours and producing 860,000 tons of coal, of which about 50 per cent was from pillars.

S.A. 139 HAULAGE & TRANSPORTATION DEPARTMENT
NELLIS MINE
AMERICAN ROLLING MILL COMPANY
Nellis, West Virginia
for having hauled the entire output of this mine aggregating more than 1,000,000 tons of coal from May 25, 1929, to December 31, 1932, with 144,831 man-hours of exposure, without a lost-time accident. The tonnages were 389,428 in 1929 (entire year); 303,318 in 1930; 287,987 in 1931; and 218,556 in 1932.

S.A. 140 ZEIGLER NO. 1 MINE
BELL AND ZOLLER COAL AND MINING COMPANY
Zeigler, Illinois
for reducing its accident-frequency rate from 340.15 in 1929 to 94.79 in 1932 and its accident-severity rate from 43.74 to 1.43. Since the last fatality on December 5, 1930, up to December 31, 1932, the mine has produced 1,735,440 tons of coal with an average of 775 employees working 1,814,416 man-hours; mechanical loading is used throughout.

S.A. 141

No. 51 MINE
ELLSWORTH COLLIERIES COMPANY,
Ellsworth, Pa.

for operating without a fatality from July 21, 1930, to December 31, 1932, employing from 789 to 642 men working 1,971,045 man-hours and producing 1,120,064 net tons of coal, of which 70 percent was mined from pillars.

S.A. 142

THE BLACK DIAMOND COAL MINING COMPANY
Birmingham, Alabama

for operating the Mossboro Mine without a lost-time accident from October 1, 1931, to December 31, 1932, with 144,925 man-hours of exposure and production 44,436 tons of coal; and the Benoit mine from August 15, 1931, to December 31, 1932, with one lost-time accident in 235,770 man-hours with production 74,987 tons of coal. The four mines of this company operated without a lost-time accident in October, 1932.

S.A. 143

BLOCK NO. 1 MINE
BLOCK COAL & COKE COMPANY
Block, Tennessee

for operating without a lost-time accident from May 26, 1931, to July 1, 1932, employing an average of 115 persons in the production of 67,832 tons of coal.

S.A. 144

WILDWOOD MINE
BUTLER CONSOLIDATED COAL COMPANY
Wildwood, Pa.

for operating without a fatality from December 27, 1930, to September 9, 1932, employing an average of 360 men working 1,330,930 man-hours and producing 1,135,321 tons of coal, of which about 60 per cent was from pillars.

S.A. 145

SOMERSET MINE
THE CALUMET FUEL COMPANY
Somerset, Colorado

for operating without a fatality from March 20, 1923, to December 31, 1932, or $9\frac{3}{4}$ years, with 1,878,384 tons of coal produced in 2,800,144 man-hours of exposure. In 1932, 124,774 tons of coal were produced in 128,579 man-hours with 6 lost-time accidents aggregating 76 lost days.

S.A. 146 COLONIAL COLLIERY COMPANY,
NATALIE, PA.
Owned by Madeira, Hill & Company,
Philadelphia, Pa.
for having the highest rating by the Pennsylvania Department of Mines, in coal production by anthracite mines in 1932, without a nonfatal roof-fall accident. This company was credited with an output of 586,937 tons, produced by 1,744,621 man-hours of employment.

S.A. 147 CRESTED BUTTE MINE
THE COLORADO FUEL & IRON COMPANY
Crested Butte, Colorado
for operating without a fatality from November 9, 1923, to December 31, 1932, employing an average of 195 men and producing 1,007,263 tons of coal.

S.A. 148 ROCKVALE NO. 3 MINE
THE COLORADO FUEL & IRON COMPANY
Canon City, Colorado
for operating without a fatality from June, 1904, to December 31, 1932, with production of 594,160 tons of coal; and for operating without a lost-time accident from June 22, 1931, to June 24, 1932, with a production of 41,154 tons of coal.

S.A. 149 STEUBENVILLE MINE
CONSUMERS MINING COMPANY
Steubenville, Ohio
for operating without a lost-time injury during 744 days, from January 4, 1931, to January 9, 1933, employing an average of 84 men working 230,732 man-hours and producing 128,630 tons of coal from a 3½-foot bed; 85 per cent was taken from pillars.

S.A. 150 ORENDA MINE
THE DAVIS COAL AND COKE COMPANY
Boswell, Pa.
for operating without a lost-time accident from December 14, 1931, to January 31, 1933, employing an average of 180 men working 279,393 man-hours and producing 129,841 tons of coal, about 60 per cent from pillars in a bed about 6 feet thick with average pitch upward of 10 per cent. This mine had its last fatality on August 10, 1929.

S.A. 151

ALLOY MINE
ELECTRO-METALLURGICAL COMPANY
Alloy, West Virginia

for operating without a fatality or lost-time accident from March 14, 1931, to March 1, 1933, handling 385,068 net tons of material, including 234,977 net tons of bituminous coal, with an average of 130 employees working 541,185 labor hours.

S.A. 152

NO. 20 MINE
JAMISON COAL & COKE COMPANY
Pleasant Unity, Pa.

for operating 1,007 days without a fatality, from September 24, 1928, to December 31, 1932, with an average of 228 men working 1,123,812 man-hours and producing 2,152,640 tons of coal from a 7-foot seam ranging from flat to 30 degrees pitch. Eighty per cent of the coal was mined from retreat workings.

S.A. 153

ELKOL MINE
KEMMERER COAL COMPANY
Frontier, Wyoming

for operating 1,266 days, from November 21, 1924, to December 31, 1932, without a fatality, with an average of 24 employees working 28,628 man-shifts and producing 536,011 tons of coal, in a steeply pitching bed about 50 feet thick. Only 7 nonfatal accidents have occurred at this mine during 8 years, with resultant loss of 429 days.

S.A. 154

ROSEBUD MINE
THE NORTHWESTERN IMPROVEMENT COMPANY
Operated by Foley Brothers, Incorporated
Colstrip, Montana

for operating an open-pit mine without a fatality and only 82 lost-time accidents from January 1, 1925, to January 1, 1933, or 8 years, with an exposure of 3,044,208 man-hours, producing about 7,320,000 tons of coal and removing approximately 15,356,000 cubic yards of overburden.

S.A. 155 NEW BLACK DIAMOND MINE
PACIFIC COAST COAL COMPANY
Renton, Washington

for operating from January 23, 1929 to December 31, 1932, without a fatality, with an average of 369 employees working 2,356,040 man-hours, and producing 1,081,702 tons of coal from a bed about 8 feet in thickness and having a pitch of 28 to 40 degrees, much of the output being from pillars.

S.A. 156 PEALE, PEACOCK, & KERR, INC.
St. Benedict, Pa.

for operating its mines Springfield 1, Victor 2, 9, 10, 15, 17, 24, 29, and 45, without a fatality from November 28, 1931, to January 1, 1933, with an average of 1,485 employees and producing 1,123,999 tons of coal, of which about 65 per cent was from pillars from a bed 30 to 44 inches thick.

S.A. 157 VICTOR NO. 45 MINE
PENN RUN COAL CORPORATION
Clymer, Pa.

for operating without a fatality from July 20, 1920, to January 1, 1933, employing an average of 115 men and producing 595,892 tons of coal from a 3-foot bed, 41 per cent of the output being from pillars.

S.A. 158 THE HAMMOND MINE
THE PHILADELPHIA & READING COAL & IRON COMPANY
Girardville, Pa.

for operating without a lost-time accident from August 31, 1932, to December 9, 1932, or 77 working days, with an average of 508 men working 312,925 man-hours, producing 158,180 net tons of coal, in a gassy anthracite mine on pitches up to 65 degrees.

S.A. 159 ROCKHILL NO. 9 MINE
ROCKHILL COAL & IRON COMPANY
Wood, Pennsylvania

for operating 329 days without a lost-time accident from December 22, 1931, to November 15, 1932, employing an average of 251 men working 416,000 man-hours and producing 154,000 tons of coal, from a bed varying from 10 to 70 per cent in pitch and under adverse roof conditions.

S.A. 160

SOUTH UNION MINE
SOUTH UNION COAL COMPANY
Uniontown, Pa.

for operating 5 years and 296 days, from March 10, 1927, to December 31, 1932, without a fatality, employing an average of 261 men for 2,665,720 man-hours and producing 3,332,101 tons of coal, of which 80 per cent was from pillars.

S.A. 161

SPRINGFIELD NO. 1 MINE
SPRINGFIELD COAL CORPORATION
Nanty Glo, Pennsylvania

for operating without a fatality from August 20, 1929, to January 1, 1933, with an average of 375 men working 2,801,993 man-hours and producing 1,233,000 tons of coal from a bed averaging 44 inches in thickness, about 66 per cent of the tonnage being from pillars.

S.A. 162

THE ST. CLAIR COAL COMPANY
St. Clair, Pennsylvania

for having the highest rating by the Pennsylvania Department of Mines per nonfatal roof-fall accident among the anthracite mines of Pennsylvania in 1932, this company being credited with producing 632,553 tons per nonfatal roof-fall accident. The man-hours of exposure were 1,286,806.

S.A. 163

IMBODEN MINE
STONEGA COKE AND COAL COMPANY
Imboden, Va.

for operating without a fatality or a lost-time accident from March 20, 1931, to July 8, 1932, or 15 months and 19 days, with an average force of 178 underground and 20 on the surface and producing 231,469 tons of coal in 509,232 man-hours of exposure.

S.A. 164

RODA COLLIERY
STONEGA COKE AND COAL COMPANY
Roda, Va.

for operating 923 days without a fatality, from June 23, 1930, to January 3, 1933, working 3,098,448 man-hours and producing 1,442,279 tons of coal, of which about 65 per cent was from pillars.

S.A. 165 STONEGA COKE WORKS
STONEGA COKE AND COAL COMPANY
Stonega, Va.

for having had but 1 lost-time accident from November 29, 1929, to December 31, 1932, with production of 203,711 tons of coke with 539,223 man-hours exposure. This plant operated throughout 1931 and 1932 without a lost-time accident, producing 85,958 tons of coke with 227,531 man-hours of exposure, and without a fatality for 14 years, producing 2,176,872 tons of coke with 5,762,180 man-hours exposure.

S.A. 166 THE UNION PACIFIC COAL COMPANY
Rock Springs, Wyoming

for reducing accidents in its eleven coal mines in Southern Wyoming; in 1932 these mines worked 2,607,216 man-hours and produced 2,045,270 tons of coal with but one fatality against six in 1931 and a total of 83 for the previous 9 years, or about 9.22 per year. Accidents (fatal and nonfatal) were 60 in 1932 against 157 in 1931.

S.A. 167 WEYANOKE MINE
THE WEYANOKE COAL AND COKE COMPANY
Lowe, West Virginia

for operating without a lost-time accident during 1932, with an average of 100 men working 146,589 man-hours in the production of 125,000 tons of coal.

S.A. 168 BEECH BOTTOM MINE
WINDSOR POWER HOUSE COAL COMPANY
Windsor Heights, W. Va.

for operating without a lost-time accident from September 26, 1931, to August 2, 1932, with production of 398,827 tons of coal. From September 26, 1931, to January 19, 1933, an average of 403 employes produced 635,821 tons of coal with only four lost-time and no fatal accidents.

S.A. 169 DOROTHY MINE
THE YOUGHIOGHENY AND OHIO COAL COMPANY
Glen Robbins, Ohio

for operating without a fatality from February 18, 1929, to December 26, 1931, employing an average of 450 men and producing 1,111,700 tons of coal with 1,961,680 man-hours of exposure in a mine having coal slightly over 5 ft. thick and a hazardous draw-slate roof of 12 to 14 inches.

S.A. 170

DEHUE MINE
THE YOUNGSTOWN MINES CORPORATION
Dehue, W. Va.

for operating 602 days without a lost-time accident from January 7, 1931, to August 31, 1932, with an average of 214 men working 531,382 man-hours and producing 356,805 tons of coal.

Metal Mines and Mining Companies :

S.A. 171

GREAT FALLS DEPARTMENTS
ANACONDA COPPER MINING COMPANY
ANACONDA WIRE AND CABLE COMPANY
Great Falls, Montana

for having worked 2,158,724 man-shifts without a fatality from 1928 to 1932, inclusive; and for working an average of 588 employees a total of 29,336 man-shifts in June, September, and November, 1932, with no accidents. This organization worked 8,635,593 man-shifts from July 1, 1915, to December 31, 1932, inclusive, and accident frequency was reduced somewhat over 80 per cent.

S.A. 172

BENNETT MINE
BENNETT MINING COMPANY
Keewatin, Minn.

for operating an open-pit mine with no fatalities and no lost-time injuries from June, 1928, to January 1, 1933, or 55 months, with an average of 52 men working 621,029 man-hours and producing 1,121,990 tons of iron ore and 638,284 tons of rock and stripping.

S.A. 173

BIWABIK MINE
BIWABIK MINING COMPANY
Biwabik, Minn.

for operating an open-pit mine with no fatalities and only two nonfatal lost-time injuries (23 days lost) from November, 1925, to January 1, 1933, or 86 months, with an average of 46 men working 974,649 man-hours, producing 1,717,601 tons of iron ore and 2,376,696 tons of rock and stripping.

S.A. 174

EUREKA-ASTEROID MINE
THE CASTILE MINING COMPANY
Ramsay, Michigan

for operating an underground mine with 1 lost-time accident from December 1, 1931, to December 1, 1932, with an average of 261 men, working 339,914½ man-hours, and producing 169,889 tons of ore. This mine operated without a fatality from December 21, 1928, to December 1, 1932.

S.A. 175

GARDNER-MACKINAW MINE
THE CLEVELAND-CLIFFS IRON COMPANY
Gwinn, Mich.

for operating an underground mine with no lost-time accidents from May 19, 1930, to January 1, 1933, or 957 days, with an average of 80 men working 417,301 man-hours, producing 178,967 tons of iron ore, and removing 3,323 tons of rock. This mine now has a record of over 1,500 days with but 1 lost-time accident.

S.A. 176

TILDEN MINE
THE CLEVELAND-CLIFFS IRON COMPANY
Ishpeming, Mich.

for operating an open-pit mine with no lost-time accidents from December 14, 1929, to January 1, 1933, or 1,113 days, with an average of 42 men working 211,410 man-hours, producing 440,010 tons of iron ore and removing 19,605 tons of rock.

S.A. 177

ALBANY MINE
CRETE MINING COMPANY
Hibbing, Minn.

for operating an open-pit mine with no fatalities and only two lost-time injuries from February 17, 1923, to January 1, 1933, or about 118 months, with an average of 52 men working 1,603,134 man-hours and producing 1,976,179 tons of iron ore and 1,350,224 tons of rock and stripping.

S.A. 178

MAHNOMEN MINE
CUYUNA ORE COMPANY
Ironton, Minnesota

for operating an open-pit mine with no fatalities and no lost-time injuries from January 1, 1930, to January 1, 1933, or 36 months, with an average of 28 men working 275,161 man-hours, producing 193,879 tons of manganiferous iron ore and 460,161 tons of stripping.

S.A. 179

HIAWATHA MINE
HANNA IRON ORE COMPANY
Iron River, Michigan

for operating an underground mine without a fatality or lost-time injury from August 6, 1930, to January 1, 1933, with an average of 155 men working 490,986 man-hours, producing 253,511 tons of iron ore, removing 12,773 cubic yards of rock, and handling 190,793 cubic yards of gravel in filling a large stope.

S.A. 180

MAHONING MINE
MAHONING ORE & STEEL COMPANY
Hibbing, Minnesota

for operating an open-pit mine with no fatalities and no lost-time injuries from May, 1930, to January 1, 1933, or 32 months, with an average of 111 men working 842,877 man-hours and producing 2,721,406 tons of iron ore and 1,904,601 tons of stripping.

S.A. 181

NO. 5 SHAFT, UNDERGROUND DEPARTMENT
THE MONTREAL MINING COMPANY
Montreal, Wis.

for operating without a fatality or lost-time accident from May 28, 1930, to December 31, 1932, or 948 days, with 604,304 man-hours of exposure in production of 692,555 tons of iron ore and rock, and in driving 11,528 feet of drift and crosscut and 4,769 feet of raises.

S.A. 182

NO. 6 SHAFT, UNDERGROUND DEPARTMENT
THE MONTREAL MINING COMPANY
Montreal, Wis.

for operating without a fatality or lost-time accident from December 12, 1931, to December 31, 1932, or 385 days, with 102,696 man-hours of exposure in production of 107,923 tons of iron ore and rock, and in driving of 3,922 feet of drift and crosscut and 2,976 feet of raises.

S.A. 183

PLYMOUTH MINE
PLYMOUTH MINING COMPANY
Wakefield, Mich.

for operating an open-pit mine with no fatalities and no lost-time injuries from December 23, 1929, to December 31, 1932, or 36 months, with an average of 66 men working 547,504 man-hours and producing 707,978 tons of iron ore and 1,164,356 tons of rock.

S.A. 184

RICHMOND MINE
RICHMOND IRON COMPANY
Palmer, Michigan

for operating an open-pit mine without a lost-time accident from January 1, 1928, to January 1, 1933, with an average of 30 men working 228,033 man-hours, producing 616,578 tons of iron ore and removing 80,276 cubic yards of stripping material. This mine has not had a fatality for 34 years.

S.A. 185

SAGAMORE MINE
SAGAMORE ORE MINING COMPANY
Ironton, Minnesota

for operating an open-pit mine with no fatalities and no lost-time injuries from August, 1929, to January 1, 1933, or 41 months, with an average of 32 men working 387,933 man-hours, producing 409,986 tons of manganiferous iron ore and 1,049,655 tons of stripping.

S.A. 186

TENNESSEE COPPER COMPANY
Copperhill, Tennessee

for operating the following departments: smelting, roasting, sintering, slag, acid, copper sulphate, flotation, railway, construction, mechanical, power, laboratory, and miscellaneous--with no accidents from January 28, 1932, to December 31, 1932, a total of 869,588 man-hours; and with but one lost-time accident in 1932 in 958,826 man-hours exposure. The Eureka mine worked 200,393 man-hours since the last accident on June 7, 1928.

S.A. 187

TOWNSITE MINE
TOWNSITE MINING COMPANY
Ironwood, Michigan
Operated by Republic Steel Corporation

for operating an underground mine without a fatality or lost-time accident from January 14, 1931, to January 14, 1933, with an average of 39 men working 90,491 man-hours in 1931 and 61,721 man-hours in 1932, producing 61,330 tons of ore and 6,250 tons of rock and stripping.

S.A. 188

WAKEFIELD MINE
THE WAKEFIELD IRON COMPANY
Wakefield, Michigan

for operating an open-pit mine with but two lost-time injuries from December 1, 1927, to January 1, 1933, with an average of 103 men working 1,394,559 man-hours, producing 2,032,585 tons of iron ore and removing 1,840,234 cubic yards of stripping material. This mine has not had a fatality since 1917.

S.A. 189

NEWPORT MINE
THE YOUNGSTOWN MINES CORPORATION
Ironwood, Michigan

for operating an underground mine with no fatalities from August 20, 1927, to December 31, 1932, or 64 months, with an average of 281 men working 3,424,523 man-hours and producing 2,391,544 tons of iron ore and 116,682 tons of rock. This mine operated 4 months of 1928 without a lost-time accident, 9 months of 1929, 7 of 1930, 3 of 1931, and 10 of 1932.

Nonmetallic Mines or Plants

S.A. 190

IRONTON MINE
ALPHA PORTLAND CEMENT COMPANY
Ironton, Ohio

for having operated an underground limestone mine from September 21, 1926 to January 1, 1933, working 1,030 days with 617,907 man-hours of exposure and mining 1,066,939 tons of stone without a lost-time accident.

S.A. 191

AVERY PLANT
AVERY SALT COMPANY
Avery Island, Louisiana

for having operated from July 3, 1931, to January 1, 1933, with 410,248 man-hours of exposure without a lost-time accident. The mine, with an average of 20 underground employees, worked 847 days without a lost-time accident.

S.A. 192

CERTAIN-TEED PRODUCTS CORPORATION
Akron, New York

for having worked an average of 150 employees in a gypsum products plant, including an underground mine, from July 17, 1931, to December 31, 1932, a total of 419,758 man-hours, without a lost-time accident. From January 8, 1931, to December 31, 1932, the mine worked a total of 219,568 man-hours without a lost-time accident.

S.A. 193

UNITED STATES GYPSUM COMPANY
Plasterco, Virginia

for having operated a mine and surface plant at Plasterco, Virginia, through the year 1932 without a lost-time accident to an average of 50 underground and 60 surface employees producing and processing approximately 450 tons of gypsum per day.

Petroleum Plants or Companies

S.A. 194

ILLINOIS PRODUCING DIVISION
THE OHIO OIL COMPANY
Findlay, Ohio

for having decreased accident frequency practically 67 per cent from 23.37 in 1927 to 7.67 in 1932 and accident severity practically 95 per cent from 4.81 to 0.26, there being but 14 lost-time accidents to 727 employees in 1,826,224 man-hours of exposure in 1932.

S.A. 195

STANDARD OIL COMPANY OF LOUISIANA
Baton Rouge, Louisiana

for operating without a lost-time accident as follows: Pipe Fitting Department worked 686,598 man-hours from January 6, 1932, to March 1, 1933; Technical Division worked 1,226,992 man-hours from July 17, 1931, to March 1, 1933; and Oil-Movement Department worked 1,256,000 (est.) man-hours from November 4, 1929, to March 1, 1933.

Individuals

S.A. 196

ALEXANDER A. ALEXANDER
Nemacolin, Pennsylvania

for acting as assistant foreman in charge of a section of the Nemacolin Mine which operated without a lost-time accident with a total exposure of 231,300 man-hours from March 14, 1930, to December 31, 1932.

S.A. 197

MATTHEW H. ANDERSON
Harwick, Pennsylvania

for supervising the operation of Section 4 of the Harwick Mine for 1 year, 4 months, and 24 days, without an accident with a total of 250,703 man-hours and with production of 208,660 tons of coal.

S.A. 198 JAMES PIERCE BUTLER
Nellis, West Virginia
for working fifty years in coal mines without the loss of a day due to personal injury.

S.A. 199 JOSEPH DUKE MELLOR CHADWICK, SR.
Steubenville, Ohio
for working 55 years in coal mines of the United States and England without incurring a lost-time injury, having been employed as driver, loader, track layer, motorman, timberman, pumper, and fire boss.

S.A. 200 CHARLES CONEZNY
Harwick, Pennsylvania
for his effectiveness as fire boss in aiding Section 4 of the Harwick mine to work 1 year, 4 months, and 24 days without an accident in a total of 250,703 man-hours and with production of 208,660 tons of coal.

S.A. 201 EDMUND GOULDER
New Philadelphia, Ohio
for having worked nearly 55 years in coal mining during which time he sustained but one slight injury causing 5 days lost time.

S.A. 202 MICHAEL HOLUPKA
Nemacolin, Pennsylvania
for having supervised the operation of a section of the Nemacolin Mine, with a total exposure of 203,854 man-hours, from March 28, 1930 to December 31, 1932, without a lost-time accident.

S.A. 203 EPH HUDSON
Coal Fork, West Virginia
for fifty-four years of continuous employment in West Virginia coal mines without incurring a lost-time accident.

S.A. 204 HENRY C. LICHTENFELD
Centralia, Illinois
for having worked 44 of the past 50 years without a lost-time accident, chiefly as a coal loader in solid shooting coal mines, this record continuing to date.

S.A. 205 WES LIGHT

Spring Fork, West Virginia

for $54\frac{1}{2}$ years of continuous employment in West Virginia coal mines without incurring a lost-time accident.

S.A. 206 MICHAEL MC NAMARA

Ishpeming, Michigan

for 50 years work in and around mines without a lost-time accident, and for efficient supervision of the safety of those in his charge.

S.A. 207 ALEXANDER MOFFAT

Steubenville, Ohio

for having worked over 60 years in coal mines of the United States and Scotland as a loader, driver, and timberman, without incurring a lost-time injury.

S.A. 208 JOSEPH PETERSON

East Pittsburgh, Pennsylvania

for working in coal mines 68 years without incurring a lost-time injury.

S.A. 209 ROBERT SLOAN, SR.

Soldier, Pennsylvania

for working 48 years in bituminous-coal mines without a lost-time accident.

S.A. 210 JOHN WESLEY SMITHERS

Sipsey, Alabama

for working forty-nine years in coal mining without a lost-time injury to himself or to persons under his supervision.

S.A. 211 LEWIS C. SMITLEY

Nemacolin, Pennsylvania

for having supervised the operation of a section of the Nemacolin Mine from December 16, 1930, to March 1, 1933, with a total exposure of 210,991 man-hours, without a lost-time accident.

S.A. 212 DANIEL THOMAS

Amsterdam, Ohio

for having worked over 58 years in practically all phases of underground coal mining without incurring a lost-time injury.

S.A. 213

THOMAS WHALEN
Wainwright, Ohio

for having worked in coal mines 58 years with but one lost-time accident. From 1883 until retirement in 1931, or 48 years, he incurred no lost-time accidents.

1934

Coal Mines and Mining Companies

S.A. 214

FLAT CREEK DIVISION
ALABAMA BY-PRODUCTS CORPORATION
Flat Creek, Alabama

for having produced 1,526,608 tons of coal without a fatality to January 1, 1934. The Gamma Mine worked without a fatality for 3 years, 6 months, and 21 days to January 1, 1934, production being 795,973 tons of coal.

S.A. 215

CRANE CREEK MINE
AMERICAN COAL COMPANY OF ALLEGANY COUNTY
McComas, West Virginia

for operating without a fatality from September 7, 1931, to December 31, 1933 (and continuing), with average employment of 526, working 2,291,232 man-hours and producing 1,496,421 tons of coal, 59 percent being from pillars.

S.A. 216

ZEIGLER NO. 1 MINE
BELL AND ZOLLER COAL AND MINING COMPANY
Zeigler, Illinois

for reducing its accident-frequency rate from 340.15 in 1929 to 74.04 in 1933 and its severity rate from 43.74 in 1929 to 2.09 in 1933. This mine had no fatalities between December 6, 1930, and February 19, 1934, inclusive, during which period it produced 2,425,824 tons of coal, working a total of 2,544,824 man-hours. A fatality occurred on the surface on February 20, 1934.

S.A. 217

BETHLEHEM MINES CORPORATION
Johnstown, Pennsylvania

for operating its 9 mines in Pennsylvania without a fatality from May 13, 1932, to December 31, 1933 (and continuing), with average employment of 2,639 persons who worked 4,021,157 man-hours and produced 2,245,421 tons of coal.

S.A. 218

NO. 51 MINE
BETHLEHEM MINES CORPORATION
Ellsworth, Pennsylvania

for operating without a fatality from July 21, 1930, to December 31, 1933 (and continuing), with average employment of 660 persons who worked 2,352,613 man-hours and produced 1,405,864 tons of coal.

S.A. 219

WILDWOOD MINE
BUTLER CONSOLIDATED COAL COMPANY
Wildwood, Pennsylvania

for operating without a lost-time roof fall accident from September, 1932, to December, 1933, with production of 762,012 tons of coal in 921,240 man-hours, and for reducing number of lost-time accidents 92.8 percent, accident frequency 89.2 percent, accident severity 97.2 percent, and cost of accidents 91.3 percent from 1930 to 1933.

S.A. 220

SOMERSET MINE
CALUMET FUEL COMPANY
Somerset, Colorado

for operating without a lost-time accident from August 31, 1932, to December 31, 1933 (and continuing), with production of 172,032 tons of coal in 190,324 man-hours worked. This mine has worked without a fatality from March 20, 1923, to December 31, 1933, producing 2,050,416 tons of coal in 2,935,624 man-hours.

S.A. 221

CLEARFIELD BITUMINOUS COAL CORPORATION
Indiana, Pennsylvania

for operating its five mines without a fatality from September 30, 1932, to December 31, 1933 (and continuing), with average employment of about 1,000 working 2,103,168 man-hours and producing 1,496,804 tons of coal. The coal bed has a dip of about 4 percent and is from 42 to 60 inches thick. About 53 percent of the production is hand loaded.

S.A. 222

THE COLORADO FUEL AND IRON COMPANY
Pueblo, Colorado
(Coal Mining Department)

for reducing its accident-frequency rate from 79.93 in 1929 and 90.95 in 1930 to 53.2 in 1933 and its accident-severity rate from 13.08 in 1929 and 8.05 in 1930 to 5.40 in 1933. Production per fatality in 1933 was 760,005 tons, or far better than the average of 199,954 tons for the coal mines in Colorado.

S.A. 223 DARBY COAL COMPANY
Evarts, Kentucky

for operating without a lost-time accident from September 1, 1932, to December 30, 1933, with employment of about 70 persons, producing 70,000 tons of coal in 39,200 man-hours of exposure. The mine has not had a fatal accident since November, 1928, and in the past 5 years has produced over 300,000 tons of coal with but 3 accidents (mashed fingers).

S.A. 224 ALLOY MINE
ELECTRO METALLURGICAL COMPANY
Alloy, West Virginia

for working without a lost-time accident from March 13, 1931, to December 31, 1933, with 682,979 "labor-hours" in which 323,619 tons of coal were mined and 189,659 tons of slate were hauled to the outside and dumped. The record was unbroken January 11, 1934.

S.A. 225 HANNA COAL COMPANY OF OHIO
St. Clairsville, Ohio

for having reduced accidents year by year from 554 in producing 1,591,297 tons of coal in 1929, to 143 in producing 2,019,476 tons in 1933, accident frequency being reduced 75 per cent. The record includes the five properties of this company and its subsidiary, the Jefferson Coal Company.

S.A. 226 HARLAN-WALLINS COAL CORPORATION
Verda, Kentucky

for working without a lost-time accident from October 1, 1932, until November 16, 1933, with average employment of 140 persons, producing 144,290 tons of coal in 253,950 man-hours from a flat bed about 40 inches in thickness, approximately 20 percent being from pillar work.

S.A. 227 LAWRENCE COLLIERY
HARLEIGH BROOKWOOD COAL COMPANY
(OPERATED BY MADEIRA, HILL AND COMPANY)
Mahanoy Plane, Pennsylvania)

for operating without a lost-time roof-fall accident from March 21, 1932, to October 25, 1933, with an average underground force of 374, of whom 143 were face miners working in 80 working places. Man-hours of exposure underground totaled 1,005,427 and tonnage 329,877, about 90 percent from pillars from 8 veins varying from $1\frac{1}{2}$ to 25 feet thick on pitch from 0 to 65 degrees.

S.A. 228

NO. 20 MINE
JAMISON COAL & COKE COMPANY
Pleasant Unity, Pennsylvania

for operating 1,197 days without a fatality, from September 24, 1928, to January 1, 1934 (and continuing) working 1,589,344 man-hours and producing 2,507,967 tons of coal in a 7-foot coal bed pitching from 0 to 30 degrees, and with 80 or more per cent of the output from retreat workings.

S.A. 229

LINCOLN GAS COAL COMPANY
Washington, Pennsylvania

for operating without a fatality from September 29, 1931, to January 19, 1934, inclusive (and continuing), with 475 men employed for 2,095,915 man-hours in the production of 1,017,156 tons of coal, all hand-loaded from a practically flat coal bed about 5 feet 2 inches thick. About 10 per cent came from pillar work.

S.A. 230

HAULAGE DEPARTMENT - NO. 1 MINE
LINTON-SUMMIT COAL COMPANY
Linton, Indiana
Jack Hays - Haulage Boss

for working without a lost-time accident from September 16, 1932, to January 1, 1934 (and continuing), hauling 485,599 tons of coal in approximately 242,800 pit-car loads and in addition about 24,000 cars of rock, gobbing it in abandoned workings, total man-hours being 45,884. On one day 3,225 tons of coal were hauled.

S.A. 231

MARY HELEN COAL CORPORATION
Coalgood, Kentucky

for working without a lost-time accident from January 3, 1933, to February 5, 1934, (and continuing), with production of 195,000 tons of coal in 109,960 man-hours.

S.A. 232

MOREA COLLIERY
MILL CREEK COAL COMPANY
(OPERATED BY MADEIRA, HILL AND COMPANY)
Morea, Pennsylvania

for operating without a lost-time roof-fall accident from June 30, 1932, to April 13, 1933, in a total of 679,238 man-hours of exposure and with production of 436,110 net tons of coal from 7 coal beds varying from 29 to 384 inches in thickness on pitch 0 to 65 degrees.

S.A. 233

NATIONAL NO. 1 MINE
NATIONAL MINING COMPANY
Morgan Postoffice, Allegheny County, Pa.
for operating without a fatality from October 23, 1929, to December 31, 1933 (and continuing), with production of 1,490,217 tons of coal in approximately 2,635,000 man-hours; and for having an excellent record as to lost-time and serious accidents.

S.A. 234

HAULAGE FORCE - NELLIS MINE
NELLIS COAL CORPORATION
Nellis, West Virginia
for working without a lost-time accident from May 5, 1929 until September 21, 1933, or 1580 days with 1,267,488 tons of coal hauled in 178,713 man-hours of exposure.

S.A. 235

TIPPLE FORCE - NELLIS MINE
NELLIS COAL CORPORATION
Nellis, West Virginia
for operating without a lost-time accident from September 30, 1927 to December 31, 1933 (and continuing), with a total of 198,449 man-hours of work in handling more than 225,000 tons of coal per year.

S.A. 236

VULCAN COLLIERY
NORFOLK AND WESTERN RAILWAY COMPANY
FUEL DEPARTMENT
Vulcan, West Virginia
for operating without a lost-time accident from September 20, 1932, to January 20, 1934 (and continuing), with average employment of 115 persons working 185,842 man-hours and producing 142,961 tons of coal. The coal bed has averaged about 56 inches in thickness, is flat, and has a rather poor roof; about 60 per cent of production was from pillars.

S.A. 237

MONITOR STRIPPING
PHILADELPHIA AND READING COAL AND IRON COMPANY
Mt. Carmel Township
Northumberland County, Pennsylvania
for operating an electric shovel stripping property without a lost-time accident from February 11, 1932, to December 31, 1933, producing 900,155 net tons of coal in 154,504 man-hours of exposure with an average force of 34. The coal bed pitches 55 degrees and is about 30 feet thick.

S.A. 238 PINE HILL COAL COMPANY
Minersville - Schuylkill County, Pa.
for operating without a fatality from January 12, 1932, to February 28, 1934 (and continuing), in the production of 1,147,146 commercial net tons of coal from 15 beds, 3-1/2 to 13 feet thick on pitch from flat to vertical averaging 35 degrees. 750 employees, 550 underground, worked 3,485,008 man-hours.

S.A. 239 PARRISH MINE
RAILWAY FUEL COMPANY
Parrish, Alabama
for operating without a fatality from August 9, 1930, to January 1, 1934, with production of 1,439,565 tons of coal in 2,398,696 man-hours. The average tonnage per fatality in the coal mines of Alabama in 1933 was 436,364.

S.A. 240 SCRANTON COAL COMPANY
Scranton, Pennsylvania
for operating without a fatality from November 13, 1932, to December 31, 1933, employing 1,385 men working 3,142,848 man-hours and producing 771,087 tons of coal of which 70 per cent came from pillars in beds varying from 1-1/2 to 15 feet thick and pitch about 10 degrees. This mine is classed as the heaviest anthracite producer without a fatality in 1933.

S.A. 241 SHERIDAN-WYOMING COAL COMPANY
Monarch, Wyoming
and
HOTCHKISS COAL COMPANY
Sheridan, Wyoming
for having produced 6,579,695.47 tons of coal to December 31, 1933, with but 2 fatalities. The Hotchkiss Mine produced 734,975.22 tons from April 1, 1920, to December 31, 1933, and the Monarch Mine 2,747,010.95 tons from December 3, 1924, to December 31, 1933, without a fatality; the Acme Mine produced 3,097,709.30 tons with 1 fatality in 1930 and 1 in 1931.

S.A. 242 BY-PRODUCT PLANT (PROPER)
SLOSS-SHEFFIELD STEEL AND IRON COMPANY
Birmingham, Alabama
for operating without a lost-time accident from June 23, 1930, to December 31, 1933 (and continuing), with employment of about 215 persons who worked 1,588,136 man-hours.

S.A. 243

SOUTH UNION MINE
SOUTH UNION COAL COMPANY
Uniontown, Pennsylvania

for operating without a fatal accident from March 10, 1927, to December 19, 1933 (and continuing), producing 3,726,982 tons of coal of which about 80 percent was from pillars, man-hours of exposure being 4,063,214.

S.A. 244

THE ST. CLAIR COAL COMPANY
St. Clair, Schuylkill County, Pennsylvania

for operating without a lost-time roof-fall accident from August 11, 1932, to January 1, 1934 (and continuing), with production of 909,705 tons of anthracite coal; approximately 410,000 tons in 1,804,383 man-hours of exposure were taken from underground operations (about 96 percent from pillar work), from 5 coal beds varying from 4 to 20 feet in thickness, on pitch from 5 to 90 degrees.

S.A. 245

ARNO COLLIERY
STONEGA COKE AND COAL COMPANY
Arno, Virginia

for working without a lost-time accident from December 2, 1932, to January 21, 1934, with 292,417 man-hours of exposure in producing 145,294 tons of coal.

S.A. 246

STONEGA COKE WORKS
STONEGA COKE AND COAL COMPANY
Stonega, Virginia

for operating without a fatality from January 1, 1919, to January 1, 1934 (and continuing), producing 2,214,342 tons of coke in 5,889,580 man-hours; and for operating without a lost-time accident from January 1, 1931, to January 1, 1934 (and continuing), with production of 123,428 tons of coke in 354,931 man-hours.

S.A. 247

STONEGA MINE
STONEGA COKE AND COAL COMPANY
Stonega, Virginia

for operating without a lost-time accident from February 21, 1933, to February 21, 1934 (and continuing), with production of 118,461 tons of coal in 284,306 man-hours. This mine has not had a fatality since February 24, 1928, and in that time produced 821,071 tons of coal in 1,970,570 man-hours.

S.A. 248

NO. 1 MINE
THE UNION PACIFIC COAL COMPANY
Winton, Wyoming

for working without a lost-time accident from May 25, 1932, to January 1, 1934 (and continuing), with production of 279,682 tons of coal in 257,968 man-hours of exposure to its approximately 119 employees.

S.A. 249

NO. 4 MINE
THE UNION PACIFIC COAL COMPANY
Rock Springs, Wyoming

for working without a fatality from April 17, 1923, to January 1, 1934 (and continuing), with production of 2,918,171 tons of coal in 3,697,896 man-hours of exposure to its average force of 218.

S.A. 250

"B" MINE
THE UNION PACIFIC COAL COMPANY
Superior, Wyoming

for working without a lost-time accident from January 8, 1932, to January 1, 1934 (and continuing), with production of 379,315 tons of coal in 377,024 man-hours of exposure to an average force of 133.

S.A. 251

KING MINE NO. 2
UNITED STATES FUEL COMPANY
Mohrland, Utah

for operating without a lost-time accident from October 17, 1932, to October 27, 1933, producing 225,621 tons of coal in 213,028 man-hours of exposure, about 30 percent production being from pillar work, largely in high coal (up to 20 feet in thickness).

S.A. 252

NO. 4 MINE
THE VESTA COAL COMPANY
California, Pennsylvania

for operating without a fatal accident from January 5, 1932, to March 1, 1934 (and continuing), producing 1,781,277 tons of coal in 2,995,952 man-hours. The accident-severity rate was reduced from 17.11 in 1928 to 6.09 in 1933. The mine has 45 men who have worked in it 20 or more years without a lost-time accident.

S.A. 253

NO. 6 MINE
THE VESTA COAL COMPANY
Denbo, Pennsylvania

for operating without a fatality from April 23, 1931, to March 1, 1934 (and continuing), with production of 902,051 tons in 1,652,470 man-hours and for reducing its accident-severity rate from 7.61 in 1928 and 22.10 in 1929 to 2.29 in 1932 and 1.93 in 1933.

Metal Mines and Mining Companies

S.A. 254

UNDERGROUND DEPARTMENT
CHAMPION MINE - COPPER RANGE COMPANY
Painesdale, Michigan

for its steady progress in reducing the accident rate every year from 2.46 accidents from all causes per 1000 shifts worked in 1926 to 0.36 in 1933. Approximately 1,010,640 man-hours were worked in 1933 and 286,808 tons of rock hoisted with no fatalities or permanent disability accidents.

S.A. 255

UNDERGROUND DEPARTMENT
EMPIRE MINE, EMPIRE STAR MINES COMPANY, LIMITED
Grass Valley, California

for operating without a fatality from June 13, 1927, to January 1, 1934 (and continuing), with total man-hours of exposure 4,027,648 to its average crew of 244 persons.

S.A. 256

JAMES MINE
JAMES MINING COMPANY
Iron River, Michigan

for operating without a lost-time accident from November 9, 1929, to December 1, 1933 (and continuing), with 339,735 man-hours worked and production of 389,873 tons of ore.

S.A. 257

NO. 5 SHAFT WORKINGS
MONTREAL MINING COMPANY
Montreal, Wisconsin

for operating without a lost-time accident from May 28, 1930, to December 31, 1933 (and continuing), or 1,313 calendar days, producing 660,012 tons of iron ore and 82,904 tons of rock in 661,520 man-hours. In addition to the various stoping operations, 12,060 feet of drifts and cross-cuts and 5,154 feet of raises were driven.

S.A. 258 ORE-MINING DIVISION
TENNESSEE COAL, IRON AND RAILROAD COMPANY
Bessemer, Alabama

for operating without a fatality from October 28, 1931, to March 6, 1933, with production of 1,351,877 tons of ore and stone; and for operating without a fatality from March 8, 1933, to February 14, 1934, with production of 1,311,032 tons of ore and stone. About 95 percent of the production was from underground workings.

S.A. 259 TENNESSEE COPPER COMPANY
Copperhill, Tennessee

for operating its entire plant (mines, smelter, railroad, etc.) without a lost-time accident from April 19, 1933, to December 31, 1933 (and continuing), with 1,058,751 man-hours of exposure. The accident-frequency rate in 1933 was 1.47, a 99.22-percent reduction over the rate of 188.25 in 1923. The Burra Burra underground mine worked without a lost-time accident from December 15, 1932, to December 31, 1933 (and continuing), with 312,127 man-hours of work.

S.A. 260 TOWNSITE MINE - TOWNSITE MINING COMPANY
REPUBLIC STEEL CORPORATION
Ironwood, Michigan

for operating without a lost-time accident from January 14, 1931, to December 1, 1933 (and continuing), with 267,327 man-hours of exposure, in the production of 125,436 tons of iron ore and 50,174 tons of rock. This underground mine also has been free of fatal accidents since July 13, 1927 or more than 7 years.

S.A. 261 MAGNA PLANT
UTAH COPPER COMPANY
Magna, Utah

for operating every day from November 2, 1932, to March 1, 1934 (and continuing), with an average force of 203, with 702,968 man-hours of exposure and without a lost-time accident in the handling of 4,377,500 tons of ore, the first time in 27 years of operation that a full calendar year (1933) passed without a lost-time accident.

S.A. 262

NEWPORT MINE
YOUNGSTOWN MINES CORPORATION
Ironwood, Michigan

for operating without a fatality from September 1, 1927, to December 31, 1933, with an average of 268 employed, working 3,701,539 man-hours and producing 2,667,739 tons of material from one of the deepest iron ore mines in the United States. This mine operated 8 consecutive months of 1933 without a lost-time accident.

Nonmetallic Mines or Plants

S.A. 263

THE BIRMINGHAM PLANT
LEHIGH PORTLAND CEMENT COMPANY
Birmingham, Alabama

for operating without a lost-time accident from August 25, 1928, to April 21, 1932, or a total of 1,334 days, in which 1,170,700 tons of stone were quarried and 3,896,432 barrels of cement were shipped, the number of man-hours of exposure being 1,631,671.

S.A. 264

IOLA PLANT
LEHIGH PORTLAND CEMENT COMPANY
Iola, Kansas

for operating without a lost-time accident from September 9, 1926, to January 1, 1934 (and continuing), a total of 2,668 days, or over 7-1/3 years, in which 1,466,258 tons of stone were quarried and 4,819,809 barrels of cement shipped, the number of man-hours being 2,428,200.

S.A. 265

ORMROD NO. 2 PLANT
LEHIGH PORTLAND CEMENT COMPANY
Ormrod, Pennsylvania

for operating without a lost-time accident from July 25, 1928, to March 4, 1932, a total of 1,317 days, with quarrying of 1,387,200 tons of stone and shipment of 4,621,188 barrels of cement, the number of man-hours being 2,222,960.

S.A. 266

ORMROD NO. 3 PLANT
LEHIGH PORTLAND CEMENT COMPANY
Ormrod, Pennsylvania

for operating without a lost-time accident from September 8, 1927, to July 15, 1930, or 1,039 days in which 737,912 tons of stone were quarried and 2,434,717 barrels of cement shipped, the number of man-hours of exposure being 1,291,032.

S.A. 267 MEDUSA PORTLAND CEMENT COMPANY
Cleveland, Ohio
for having 4 of its plants in the "1000-Day Club" of the Portland Cement Association, indicating that these 4 cement plants have operated without a lost-time accident for 1000 or more days up to and including January 1, 1934.

S.A. 268 POTASH COMPANY OF AMERICA
Carlsbad, New Mexico
for sinking its No. 1 shaft to a depth of 1,098 feet without a lost-time accident. Man-hours of exposure were 46,500 and the work was done between February 2, 1933, and December 30, 1933.

Quarries

S.A. 269 LIMESTONE QUARRY, CRUSHING AND SCREENING PLANT
INLAND LIME AND STONE COMPANY
Manistique, Michigan
for operating without a lost-time accident from November 18, 1932, to February 1, 1934, with employment of about 112 persons, who worked 306,200 man-hours.

Associations

S.A. 270 PORTLAND CEMENT ASSOCIATION
for having 19 cement plants in its 1000-Day Club, indicating that on January 1, 1934, all of these plants had operated without a lost-time accident for 1000 or more days, 2 having operated more than 2000 days and 9 more than 1400 days without a lost-time accident.

Mills or Smelters

S.A. 271 DUCKTOWN CHEMICAL AND IRON COMPANY
Isabella, Tennessee
for reducing accident frequency from 64.41 in 1929 to 5.16 in 1933 and accident severity from 10.96 in 1929 to 0.077 in 1933, man-hours being 1,505,998 in 1929 and 581,425 in 1933. Isabella Mine had accident severity 1.55 in 1929 against 0.33 in 1933 and accident frequency 91.79 in 1929 against 19.08 in 1933, ore tonnage being 88,356 in 1929 and 116,173 in 1933.

Miscellaneous

S.A. 272

IRONTON PLANT
COLUMBIA STEEL COMPANY
Provo, Utah

for operating without a lost-time accident from November 24, 1932, to December 31, 1933 (and continuing), with a force of 283 men, or an average of 168 men, working 488,357 man-hours.

S.A. 273

COAST RANGE DIVISION
HETCH HETCHY WATER SUPPLY SHAFT SINKING AND TUNNELING
Livermore, California

for sinking the Thomas, Mocho, Indian Creek, and Escobar Shafts a total of 1,555 feet, and for driving 17-1/4 miles of tunnel (from Thomas Shaft 4-1/4, from Mocho Shaft 4-1/2, between Valle and Indian Creek Shafts 5, between Alameda and Irvington Portals 3-1/2) about 15 feet in diameter, with excavation of 776,870 cubic yards of material in 8,075,760 man-hours without a fatality.

Individuals

S.A. 274

ALEXANDER A. ALEXANDER
NEMACOLIN MINE - BUCKEYE COAL COMPANY
Nemacolin, Pennsylvania

for acting as assistant foreman in charge of a section of the Nemacolin Mine, which operated with a total exposure of 261,680 man-hours from March 14, 1930, to January 5, 1934, without a lost-time accident.

S.A. 275

JOHN W. BAILY
Burgettstown, Pennsylvania

for having worked 62 years in coal mines in the Panhandle District of Pennsylvania without a lost-time accident, retiring uninjured in 1933, at the age of 72.

S.A. 276

BROWNLOW ESTES
Bardo, Kentucky

for having worked $55\frac{1}{2}$ years in coal mines in Kentucky without a lost-time accident.

S.A. 277

HARRY C. KNIGHT
St. Johns, Illinois
for having worked without a lost-time accident for the last 57 of his approximately 62 years of employment in coal mines around DuQuoin, Illinois.

S.A. 278

DAVID MORGAN
MINE NO. 5
VESTA COAL COMPANY
Vestaburg, Pennsylvania
for acting as assistant foreman in charge of about 110 men who worked without a lost-time accident from October 29, 1931, to February 6, 1933, with 225,812 man-hours of exposure.

S.A. 279

DAVID MOYES
NO. 5 MINE
VESTA COAL COMPANY
Vestaburg, Pennsylvania
for acting as assistant foreman and operating his section of the mine without lost-time accidents from December 10, 1931, to July 22, 1933, man-hours of exposure being 226,236.

S.A. 280

HENRY A. RENINGER, SPECIAL REPRESENTATIVE
LEHIGH PORTLAND CEMENT COMPANY
Allentown, Pennsylvania
for successful leadership in the safety movement especially in the cement industry. Under his direction in charge of accident prevention, every plant in the Lehigh Portland Cement Company has a record of having worked at least one calendar year without a lost-time accident; and the 15 plants of the Lehigh Portland Cement Company have had 41 plant-calendar-years of operation without a lost-time accident.

S.A. 281

DANIEL THOMAS
Amsterdam, Ohio
for having worked without a lost-time accident for 59 years and 2 months in underground coal mining, retiring from active service on December 13, 1933.

S.A. 282

ELGIE UNDERWOOD
NO. 4 MINE
VESTA COAL COMPANY
California, Pennsylvania
for acting as assistant foreman over a section of the mine which operated without a lost-time accident in 240,087 man-hours of exposure.

S.A. 283

WILLIAM WILKERSON
DeSoto, Illinois
for working practically 75 years without a lost-time accident in coal mines of England and the United States, from 1856, when he was 9 years old, to 1930, when he retired at the age of 83.

CONCLUSION

Although there were about 17 major coal-mine disasters per year with average fatalities of 478 annually from them in the period 1906-10, inclusive, as given in the opening paragraphs of this paper, there was but 1 major explosion fatality in the coal mines of the United States in 1933 and in it but 7 lives were lost and there were but 2 major coal-mine disasters in 1934, an explosion with 17 fatalities and a mine fire with 5 deaths. Although there were 2,658 total coal-mine fatalities annually in the period 1906-10, inclusive, there were but 1,064 such fatalities in 1933 and about 1,185 (tentative figures) in 1934. Unquestionably the safer operation of coal mines of which Dr. Joseph A. Holmes had visions when he became the leader of the U. S. Bureau of Mines in 1910 is now at least in part a reality.

The mining industry is becoming "safety conscious", although it must be admitted that the improvement has not kept pace with safety achievement in other industries. Unquestionably the awards given by the Joseph A. Holmes Safety Association have played an important part in the recent progress of the safety movement in the mining and allied industries of the United States, and the material reduction of accidents in those industries in the past few years has had a considerable part of its impetus in the inspiration conveyed to the mining industry by the publicity given the extremely fine safety accomplishments of the recipients of the awards of the association.

The assembling and checking of the accuracy of the wordings of the awards as contained in this paper have been done by Mrs. M. J. Schutrumpf and Mrs. Louise Pedlow, both of whom for the past several years have done much of the considerable amount of work entailed in the operation of the association.

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

MAINTAINING THE PERMISSIBILITY OF ELECTRIC CAP LAMPS[1]

By D. H. Zellers[2] and A. B. Hooker[3]

INTRODUCTION

Since its inception the United States Bureau of Mines has fostered the development of portable mine lamps. Although there is still much to be desired with respect to illumination in coal and metal mines and the replacement of open lights has been slow, the Bureau has been given credit for assisting materially in the development and introduction of the safe and efficient portable mine-lighting equipment available today.

Much of the work conducted by the electrical section of the Bureau entails approval tests of various types of electrical equipment, including lamps, to be used in atmospheres that may contain methane or coal dust in explosive proportion. If a cap lamp meets the requirements for safety, efficiency, and adequacy, as published in Schedule 6B,[4] it is approved and is generally known as a "permissible" lamp. The terms "approved" and "permissible" often are used interchangeably. The manufacturer must put an approval plate on each approved lamp, showing it has met the schedule requirements. The approval plate is not a guarantee that the lamp is safe. However, if the lamp, once in service, has not had any parts changed or improperly assembled or if parts that wear out or depreciate have been properly replaced it should still be safe, efficient, and adequate for the service intended. Virtually all electric cap lamps in service today in the United States and a great many that have been sent to foreign countries bear the approval plate of the United States Bureau of Mines. Although many explosions have been attributed to open lights none has been charged against the permissible cap lamp. Nystagmus, a disease of the eye attributed to working under insufficient illumination, is practically unknown among American miners, although it is quite prevalent among European miners.

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6832."

2 Assistant electrical engineering aid, U. S. Bureau of Mines.

3 Associate electrical engineer, U. S. Bureau of Mines.

4 Bureau of Mines Permissible Electric Cap Lamps; Procedure in Testing, Fees Charged, and Requirements for Approval: Sched. 6B, December 1926, 7 pp.

The Bureau's first consideration is safety; to meet the schedule requirements an electric cap lamp must therefore embody a safety device designed to interrupt the electrical circuit should the bulb glass be broken and thereby eliminate the explosion hazard of an exposed glowing filament. Battery covers that are removed for charging must be equipped with magnetic or other equally effective locks; headpieces must also be equipped with a lock or seal to prevent the exposure of live terminals without unwarranted tampering. The battery must contain nonspilling devices to prevent the spillage of electrolyte from the vent plugs and possibly serious flesh burns or damage to clothing. The reflector must be designed and the bulb located to distribute the light properly without throwing objectionable dark spots or rings or causing undue strain on the eyes of the wearer or his fellow-workers.

Efficiency and adequacy are additional considerations. The bulbs supplied for use with cap lamps submitted for approval must meet requirements for life and physical, electrical, and photometric uniformity; the cord, battery case, and headpiece must meet requirements for mechanical strength and durability, and the battery must have sufficient capacity to supply ample energy throughout a full working shift.

There are two general ways of procuring cap lamps - rental and outright purchase. A large percentage of the newer lamps are on a rental basis. Although only a small percentage of lamps are purchased the data on maintenance of lamps apply particularly to such installations.

MAINTENANCE

Batteries

The battery is the power plant of the cap lamp. The maximum amount of light cannot be obtained unless the power plant is in perfect condition. Battery efficiency, therefore, is of first importance when efficiency of the lamp as a whole is under consideration. All permissible cap lamps are either of the alkaline or the lead-acid storage-battery type. The alkaline cap-lamp battery is relatively long-lived, having a rated life of 70 to 80 months; the rated life of the lead-acid battery is 18 to 24 months.

It should be understood that battery plates gradually deteriorate and that during the latter half of the normal life of a cap-lamp battery the capacity decreases considerably. As a result, the lamp gives less light, and usually the time of burning is reduced seriously. Loss of burning time can be compensated for by using lower-current bulbs, but the lamp still will give less light.

Charging.- The service obtained from a lamp battery depends much upon how it is charged. The charging rate should be enough to stimulate the necessary plate action yet not high enough to overheat or dislodge active plate material.

The "constant-current method" generally is employed for charging alkaline batteries; the supply is usually of practically constant voltage, and a variable resistance is provided in the charging line. To maintain constant current this resistor must be readjusted periodically to maintain the supply voltage at a higher value than the increasing E.M.F. of the batteries. At each adjustment the current should be set a little above the normal value so that at the next adjustment the rate will not be much below normal, thus maintaining an average of the normal rate recommended by the manufacturer. The charging rate should always be that specified by the manufacturer, but the charge should be continued until 15 to 20 percent excess has been returned over and above the capacity taken from the battery during the previous discharge or until a maximum voltage has been reached and maintained for an appreciable time. The specific gravity of an alkaline battery does not change appreciably during charge, so gravity readings will not adequately indicate the state of charge; however, it can be determined with a voltmeter. The voltage of a fully charged alkaline battery will range from 1.80 to 1.90 volts per cell at the normal charging rate, depending on the temperature, age of cells, condition of electrolyte, etc., but this is of no consequence because the idea is to reach and maintain the normal maximum voltage. An abnormally high voltage reading indicates excessive resistance, which usually is due to poor contact between clip and battery posts but, if not, indicates high internal resistance in the battery assembly. An abnormally low voltage reading indicates that one cell probably is shorted between the valve and pole nut on the rack charging clip.

The constant-current method explained under charging of alkaline batteries may be employed for charging lead batteries, but the constant-potential or constant-voltage method is used quite generally in the newer installations. Constant-potential charging operates automatically and requires a minimum amount of attention and a shorter time for a complete charge. It also requires a source of constant voltage a little above the individual battery voltage, with a large enough current capacity to supply the number of batteries to be charged. Specially designed motor-generator sets, the generator of which has the desired characteristics, are available for this service. The constant-potential method of charging is especially suitable for lead-acid cap-lamp batteries. A battery can be put on charge in any state of discharge, and the charging rate will be controlled automatically at the proper values until the battery again becomes fully charged. Overcharging is impossible, except by increasing the terminal voltage of the generator, and undercharging is unlikely, unless the charging contacts are poor, because a large percentage of the charge is taken during the first few hours, after which the rate tapers rapidly until toward the end it amounts to only a trickle charge. Where this method is employed the terminal voltage of the generator should be set at the value recommended by the battery manufacturer.

Whether a lead-acid battery is charged from a constant-potential or a constant-current supply the state of charge can be determined from specific-gravity readings. With the battery discharged the gravity will read approximately 1.150 and when fully charged, from 1.280 to 1.300. The best indication

of state of charge, however, is obtained with the voltmeter. As with alkaline batteries, the idea is to reach and maintain a maximum-charge voltage. The voltage of a fully charged lead-acid battery will range from 2.40 to 2.50 volts per cell while on charge at normal charging rate.

Watering.- Batteries require water about once a week when in constant use. Use nothing but distilled water. Never fill cells above the proper level, for if filled too high the solution will be forced out during charge. When the valves of alkaline-type batteries are removed for the periodical watering they should be dropped into a pan of hot water. The carbonate that accumulates in the valves is readily soluble in the water, and the valves will thus be clean and in proper working order upon replacement. When the valves are replaced make sure that all seat properly. When the rubber-valve gasket is in good condition considerable force will be required to lock the valve in place. Always renew worn valve gaskets and tighten the pole-nut gaskets, renewing any of these found defective. These precautions are essential to prevent spilling of electrolyte. After the valves have been replaced it is a good policy to wash the top of each battery under a hot-water tap, pouring off any excess that might have been spilled into the battery casing. Where washing facilities are not available be sure there is no free electrolyte on the battery top or in the casing; then wipe all parts clean and dry. After the batteries have been watered they should be given a short brush-up charge.

Renewal of electrolyte.- The electrolyte in alkaline batteries is a solution of potassium hydroxide and a catalyst. Because of dilution and contamination it is desirable to renew the electrolyte every 8 to 12 months; specific-gravity readings taken to determine its condition have no value unless they are taken with the electrolyte at the normal level. Before solution is renewed discharge the battery to 0.5 volt per cell at normal rate, remove valves and valve gaskets, pour out half the solution, shake vigorously, and pour out the remainder. Never rinse cells with water. If rinsing is considered necessary use the old solution after straining to remove dirt. Never let the cells stand empty; refill them as quickly as possible with the solution recommended by the manufacturer. Inspect the valve and pole-nut gaskets to ascertain that all are leakproof. Wash the battery top under a hot-water tap, pouring off any excess water that might have run into the battery casing. Always use clean utensils when renewing solution; never use any that have contained lead battery acid. After solution is renewed give the batteries an overcharge at the normal charging rate before putting them back into service. Always insure that a battery is clean, dry, and fully charged before issuing it to a miner.

The electrolyte in the lead-acid batteries is sulphuric acid solution. Because of the relatively short life of lead battery plates renewal of the electrolyte usually is not necessary during the life of the plates.

Rejuvenation.- Owing to enforced periods of idleness, insufficient daily charge, trickle-charging, low temperatures, or contamination of electrolyte, alkaline batteries may lose capacity and become sluggish. Loss of

capacity generally can be regained by subjecting the batteries to a rejuvenation process. The recommended procedure follows: Discharge the batteries by letting the bulbs burn in the headpieces until the voltage across the battery terminals with the bulbs drawing current reaches 0.5 volt per cell. Then short-circuit the batteries for several hours through low resistance - a short piece of no. 8 wire fastened securely to the terminal posts is suitable for the purpose. Finally give them an overcharge (normal rate of charge for several hours longer than normal). The batteries can then be put back into service but will not have normal capacity until they have been through several charge and discharge cycles. It is therefore better policy to discharge a battery and give it another overcharge, after short-circuiting before returning it to service. If no substantial improvement results from this process repeat it. As a last resort, if still no improvement is noted, change the solution as directed under renewal of electrolyte.

Lead batteries of the pasted-plate variety lose capacity owing to dislodgment of active material from the plates and by sulphation. The "Ironclad" type of positive plate in which the active material is held in horizontally slotted hard-rubber tubes was developed to forestall excessive dislodgment. More recently a battery that does not contain free electrolyte has been developed. In this battery the electrolyte is absorbed in thick sponge wood separators held close to the plates. This latter development eliminates the washing action of free electrolyte, which was the main cause of dislodgment of active material.

Some evidences of sulphation are: Continued low specific gravity; continued low open-circuit voltage; inability to take normal charge on account of increased internal resistance; and the light color of either or both positive and negative plates, the last being the best indication. Sulphation can be remedied, if it has not gone too far, by giving the battery several complete discharge (to 1.7 volts per cell) and charge cycles.

Headpieces

The headpiece houses the safety device and contains a switch, together with the bulb, reflector, and lens, all of which affect the efficiency of the lamp. The safety device embodies contacts that influence the resistance of the bulb circuit. The switch contacts usually are of the wiping variety designed to clean themselves automatically, but sometimes they become corroded or oxidized and the moving member occasionally works loose. The headpiece should be inspected periodically to insure that the contacts are clean and tight and all terminals soldered properly or fastened securely. The safety of the unit depends upon the bulb ejector; this should be checked to insure that it has not become blocked or otherwise made ineffective.

The maximum reflecting efficiencies of new headpieces of permissible cap lamps will range from 80 to 85 percent. Both the reflector and the lens absorb some of the light emitted by the bulb. It is important that these absorptions be kept as small as practicable; the headpiece should therefore be kept sealed and in its original permissible condition.

The miner should never have access to the interior of a headpiece, and no person should be authorized to make any alterations in a headpiece that will affect the distribution of light.

Bulbs

The approval of each permissible cap lamp covers one or more bulbs for use with that lamp. Approved bulbs are plainly marked with a Bureau of Mines symbol number at the base - BM-20C, BM-25B, etc. The numeral in each symbol is the approval number of the cap lamp, and the letter following the numeral denotes a modification of the originally approved bulb. Where more than one bulb has been approved for a lamp the current and voltage ratings of each are different although outwardly they are alike; the shape and size of the main bulbs of all cap lamps in this country are uniformly the same.

A 1.0-ampere bulb which operates satisfactorily on a new battery may be too heavy a drain on a depreciated battery, in which case a lower-current bulb is sometimes substituted, with a corresponding loss of light. If the higher-current bulb is used more light is emitted in the early part of the shift but little or no light at the end. However, before changing to lower-current bulbs the real cause of any diminution of normal amount of light should be determined. It is important to know whether the cause is normal deterioration of the battery or some correctable condition, such as poor condition of the bulb or reflector or external resistance. It may not be necessary to substitute lower-current bulbs, and the advantage of the increased light given by the higher-current bulb will be retained.

All approved bulbs have met the Bureau's requirement of at least 200 hours' life. One make of permissible cap lamp contains 2 bulbs, 1 of which is an auxiliary bulb of the flashlight type for emergency use. The major bulb used in this lamp has 2 similar filaments, the aggregate life of which is the required 200 hours. Other permissible cap lamps are equipped with 1 double-filament bulb having 1 major and 1 minor filament; the life of the major filament must be 200 hours. No requirements are made for the life of the minor filament, because this filament is primarily for emergency use.

It is suggested that 1 filament of the double major-filament bulb be burned for approximately 100 hours and then the second filament switched on before the first was burned out so that the miner may have normal light to finish his working shift when the second filament burns out.

The end of a bulb's useful life usually is less than its ultimate or "burn-out" life. Blackening of the bulb glass indicates the end of useful life. It represents a loss of material from the filament; which becomes smaller and has higher resistance than when new; consequently the bulb draws less current from the battery and gives less light. Blackening also causes a loss of light through the bulb glass. Thus, toward the end of its life a cap-lamp bulb may give 30 percent less light than when it was new. If, as generally agreed, a worker's efficiency and safety depend to a great extent upon the amount and quality of light available, using cap-lamp bulbs until they burn out is not real economy.

Reflectors

Shape, finish, and position of reflector are the main factors that determine distribution of light. Reflectors that give the most desirable distribution underground are of the diffusing type. No certain type is compulsory, but since the desired distribution of a diffused light is produced so readily by the diffusing type of reflector it has been adopted in all permissible cap lamps in use today. All reflectors of permissible cap lamps are made of aluminum and have a mat finish produced either by sand-blasting or by a chemical treatment. Two modifications of permissible electric cap lamps equippod with polished, plated-brass reflectors have been approved for limited use in inspection service, but these are special lamps with special approvals and are not covered by the regular cap-lamp schedule.

Mining men are continually attempting to improve their lights by altering the original reflector finish. The most common practice is to rub the reflecting surface with a fine abrasive to obtain a polished finish. The popular opinion seems to be that when the light is concentrated into a small spot it has been improved. The spot produced only appears brighter in contrast to the dimmer light surrounding it but actually is not as bright as the central area of the field produced by a standard diffusing reflector. One outstanding case has been called to the Bureau's attention. This reflector had been given a coat of black enamel which resulted in a reddish-black, glossy finish. The glossy finish had the effect of producing a field somewhat similar to that produced by a highly polished reflector - a bright central spot surrounded by an area of dim light - and permitted only about 35 percent of normal illumination. This case is unusual, but it serves to show how far the miner, usually not versed in the subject of illumination, can be misled in his efforts to improve his light. The individual who made that change actually believed he had improved his light. He probable sought a softer light, but he actually subjected himself and his fellowworkers to constant danger and glare in traveling and working under the poor light he produced for himself by altering his cap-lamp reflector.

As has been stated, these "improvements" usually result in a loss of light. There is no perfect reflector, one that reflects 100 percent of light emitted by the bulb. Those furnished with permissible cap lamps have been developed in laboratories where all facilities necessary to determine the proper features are available. To alter the reflectors is to defeat the purpose of all this work.

Standard permissible cap-lamp reflectors absorb 10 to 15 percent of the light produced by the bulb. Scratched or soiled reflectors may absorb as much as 30 percent of the light and reflectors that have been rubbed, as much as 40 percent. Hence, the reflector accounts for a loss of 20 to 30 percent of the total available light.

These excessive losses result in low efficiencies, which can and should be avoided. Refinishing in the field is not satisfactory; reflectors that have become soiled or scratched should be replaced and returned to the lamp distributor, who has facilities for restoring the original finish. Changing

the finish of the reflector is the most common alteration of the permissible cap lamp at the mines and should be strongly discouraged.

Polished reflectors have not been approved for use in permissible cap lamps because they do not distribute the light to the best advantage of the average miner in the performance of his regular duties. However, the Bureau is aware that many polished reflectors are being used today - too many, in fact. Some operators believe that certain duties in a mechanized mine require concentrated light. For such work as haulage and operation of cutting or loading machines in especially dusty atmospheres or for the purpose of signaling it is perhaps aafer to use the concentrated light as produced by the polished reflector. On the other hand, the average miner should not be permitted to use one. In the first place it produces excessive glare, causing discomfort to the eyes and temporary blindness for an instant or so, the space of time in which accidents usually occur. In the second place the polished reflector absorbs more light than the standard diffusing type and therefore reduces cap-lamp efficiency. The finish of some polished reflectors deteriorates more rapidly than that of the diffusing types; consequently the light in the outer portion of the field soon diminishes to a point where an inadequate walking light is produced.

It is well to remember that a cap lamp equipped with a polished reflector is not permissible. If steps were taken to allay the dust caused by mechanical operations in rooms, rather than resorting to the use of polished reflectors, several hazards might be eliminated instead of another created through glaring lights. More efficient locomotive headlights or stationary illumination for track and switches would relieve the need of spotlights for snappers.

Lenses

Any lens will absorb some of the light emitted by the bulb. Lens supplied with permissible cap lamps are made of clear glass 0.060 to 0.1 inch thick with plain surfaces. This type was selected because of its low coefficient of absorption. The maximum amount of light absorbed usually is less than 5.0 percent. These original lenses have been replaced by many other types in attempts to improve the light. As when the reflector finish is altered, the "improvement" usually results in loss or undesirable distribution of light.

Three-ply "safety-glass" lenses, the central ply of which is a cellulose compound, have practically the same coefficient of absorption when new as standard lenses, but as the cellulose compound oxidizes and causes it to turn yellow the absorption increases. This type of lense once was used in permissible cap lamps and is now used by the British in headpieces without safety devices. Safety-glass lenses are still available, but their use is not recommended because of deterioration, which results in a gradual loss of efficiency; incidentally, no particular advantage in safety is gained.

At certain mines a concavo-convex lens, clear in the center with a rough beady finish 3/16 inch wide around the outer edge, has been substituted under the assumption that it improves the light, whereas it actually absorbs over 2.5 percent more light than a standard lens. The plano-convex type as

used in some flashlights also has been adapted to cap lamps. This lens in a headpiece equipped with a standard diffusing reflector produces a small concentrated area or spot. This type absorbs an excessive amount of light and produces very undesirable distribution; it increases the area illuminated yet decreases the area of adequate illumination, because the light thrown beyond 130° is wasted and the increase in light in the center is gained at the expense of illumination outside the center. The double convex and the concavo-convex lenses give results similar to those of the plano-convex lens.

A "daylight" lens was developed for men working at picking tables to enable better differentiation between the coal and slate. It produces a blue light, which has the same effect as sunlight with respect to reflection of colors as seen by the eye. However, when a daylight lens is used for proper selection of color the amount of light must be increased in proportion to the absorption coefficient of the blue glass used to produce it. This cannot be done advantageously in the cap lamp, owing to the limiting conditions; what might be gained in color perception is lost in quantity of light, making the daylight blue lens impracticable for use in the cap lamp. This lens did not affect distribution of light appreciably but absorbed almost 25 percent more light than a standard lens.

Cords

The cord or cable conducts the electrical energy from the battery to the headpiece. Flexible rubber-covered cords that have proved their practicability with respect to carrying capacity and mechanical strength are supplied with permissible cap lamps. The average life of cap-lamp cords is estimated at approximately 8 months. The strands ultimately break through corrosion and flexing; broken strands reduce the carrying capacity of the conductor and set up resistance to the flow of electricity from the battery which reduces the voltage across the bulb terminals. Usually the battery electrolyte creeps under the insulation and causes corrosion; this creepage can be prevented by sealing the ends of the cord with pitch compound. Perspiration also causes some corrosion but mainly swelling and deterioration of the rubber insulation. Swelling of the cord sheath destroys the binding effect of the insulation, making the copper strands more susceptible to breakage due to flexing.

Cables should be given more attention than is generally believed necessary and replaced or serviced when found defective. When corrosion has started at the battery end of a cable that end should be cut off, but if discovered early it should not be necessary to cut off more than a half inch. The end can be cut several times, or until the cable has become too short. Terminal lugs should always be resoldered. Corrosion of terminals can be kept at a minimum by preventing electrolyte from getting into the battery cover. One manufacturer has considered this in the design of his battery and piped the gas formed in charging to the outside of the battery. In lamps that have removable covers the plate terminals should be kept tight and valves should be kept in good working order. Any electrolyte that passes through valves that are normally open during a charge or any spillage during filling should be washed off.

Contacts

The importance of keeping external resistance in the electrical circuit at a minimum cannot be stressed too strongly. Loose, dirty, or corroded contacts also cause resistance in the circuit. All lugs, etc., that normally are soldered should be soldered if replaced. All contacts, both on top of the battery and headpiece, should be kept clean and tight. The carbonate that is deposited on the metal parts on top of the cells of alkaline batteries can be washed off under a hot-water tap. Abrasives should not be used for polishing contacts should be avoided, as most metal parts are plated and abrasives remove the plating.

Distribution of Light

The normal field of light from a permissible cap lamp may be divided into three areas. The first is a small, central area of concentrated light from the filament itself, which is normally in the center of the headpiece. This area, usually 6° to 8° in extent, is surrounded by a bright area approximately 20° in extent, which is bright enough to accommodate the performance of ordinary duties. These areas combined constitute the "working light." The rest of the light to the edge of the beam, the total angle of which is limited to 130°, is bright enough to permit safe traveling. This area is considered the "walking light." There are no sharp lines of demarcation between these three areas, the light of one shading into the next and giving a pleasing distribution with the minimum of annoying glare. Then, too, the entire field is free from dark spots or rings.

The useful product of an electric cap lamp is light. Almost every part of the lamp is closely related and bears on the amount or quality of the light and the general practicability of the lamp. Much research work has been done to obtain a desirable distribution of light from cap lamps for general service underground. Many lamp users in the field have attempted to improve this distribution of light, but the Bureau does not know of one that has been succesful. Usually such attempts result in less desirable distribution and glare, together with either an actual loss of light or a waste of available light. It is a waste of light to increase the light beam beyond an angle of 130° as any light beyond that angle is outside the normal field of vision and serves no useful purpose.

Conclusions

The Bureau of Mines became interested in electric cap lamps because it saw in them a safer and more efficient means of lighting mines than with open-flame lamps. The Bureau undertook the sponsorship not only of the safety but also of the practicability of electric cap lamps in order that these lamps might be adopted as early and as widely as possible. The need for safe illumination still exists, as more than half of the miners in the United States still use open lights; the Bureau is still actively behind the further use of electric cap lamps.

The operator should insist that his lamps be kept in good working order for three reasons: (1) Better lighting means greater safety to the user, fewer accidents, and less compensation for injuries; (2) better lighting pays in increased tonnage and cleaner coal; (3) if the lamps are not properly maintained they lose favor and their introduction is retarded.

The keyman in proper lamp maintenance is the lamp attendant. The operator can do much by selecting proper lamp attendants and in furnishing enough help and supplies to do the job adequately. The lampman should keep account of the repairs made on each lamp. Such an account will "show up" the careless or malicious user.

Observations and data of various lamp installations indicate that an attractive lamphouse, cleanly and neatly maintained, inspires careful use of lamps. In some places a system of prizes for exceptionally good care of lamps will help; in others a system of charging all breakage of lamps against the individual miner is more effective.

Each user should report any damage to his lamp, a burned-out filament, or any flickering of his light. Any just complaints should be given courteous attention by the lamp attendant.

The permissible cap lamp is an ideal source of illumination for the purpose intended. It follows each movement of the head, directing the light on the objective sought, and never causes a man to cast a shadow in the path of his light. It gives him light at his feet, which is essential for safe traveling, and yet does not waste light by throwing it outside his field of vision. Its primary purpose is to give adequate light and remove the hazards attending the use of open lights. A cap lamp in a permissible condition embodies all the features designed to accomplish that end.

Safety can be assured by keeping the battery cover and headpiece locked, sealed, or properly fastened in place, as the case may be, and all the parts in working order. Maximum efficiency can be maintained by keeping a close check on the condition of the battery, the bulb, and the reflector and current-carrying contacts.

The Bureau does not infer that permissible cap lamps are perfect or that the ultimate in safety or efficiency has been attained; as a matter of fact, cap lamps are continually being improved. Neither does it infer that the layman is incapable of improving a permissible cap lamp; many important developments have resulted from suggestions of the user in the field.

Before any contemplated alterations of permissible equipment are made it is recommended that the manufacturer be consulted. He will undoubtedly appreciate any practical suggestions for improvement in design or construction. The manufacturer of a cap lamp is the one to whom the Bureau of Mines approval is issued. Any changes made in a permissible cap lamp or any other piece of permissible electrical equipment, for that matter, must be initialed by him. He must then submit specifications of the proposed changes to the Bureau for

an extension of his approval covering the proposed changes. Where safety or adequacy are involved further tests are made by the Bureau to insure adequate standards for permissible equipment.

It is hoped that this paper will encourage and stimulate a greater interest in maintenance of portable electric lamps and discourage the use of unapproved parts, which usually decrease the efficiency of the lamps and may result in a potential hazard.

I. C. 6835

March 1935

Department of the Interior

UNITED STATES BUREAU OF MINES
John W. Finch, Director

INFORMATION CIRCULAR

REVIEW OF LITERATURE ON EFFECTS OF BREATHING DUSTS WITH SPECIAL REFERENCE TO SILICOSIS

PART I

BY

D. Harrington and Sara J. Davenport

I.C. 6835
March 1935

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

REVIEW OF LITERATURE ON EFFECTS OF BREATHING DUSTS, WITH SPECIAL REFERENCE TO SILICOSIS[1]

PART I

By D. Harrington[2] and Sara J. Davenport[3]

CONTENTS

1 The Bureau of Mines will welcome reprinting of this information circular, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6835."

2 Chief, health and safety branch, U. S. Bureau of Mines.

3 Principal translator, U. S. Bureau of Mines.

INTRODUCTION

This circular presents part I of a review of the literature on effects of breathing dusts, with special reference to silicosis, largely in the mining and allied industries. The literature on this subject is so extensive that no attempt has been made to include all published material but only to assemble some of the more outstanding data on several aspects of the subject. Parts II and III will deal with prevention and treatment of dust diseases and some of the economic and legal aspects of dust diseases in industry, with special reference to mining.

Dust diseases are much before the public at present, and there is good reason to believe that the information on the subject available to the layman is extremely meager; even those rated as experts usually have a more or less theoretical conception of the diseases, their causation, remedies, and prevention, rather than actual experience with them. Until recently little attention has been given to prevention, and the usual attitude of the engineer, upon whom the main reliance for prevention ultimately must devolve, has been to let "sleeping dogs lie" or, more definitely, to "let well enough alone." However, the "laissez faire" attitude no longer is tenable, and in the past few years numerous conditions have caused those engaged in industry, including mining, to bring the subject before the public with a view to ascertaining the facts upon which to formulate remedial measures, primarily preventive.

CHAPTER 1. DEFINITION AND CLASSIFICATION OF DUSTS

According to Webster's Unabridged Dictionary dust may be defined as fine, dry particles of earth or other matter so comminuted that they may be raised and wafted by the wind; that which is crumbled to minute portions; fine powder. In 1876 Richardson (1)[4] included in the term "dusts" all those fine and solid particles thrown off from various substances in the processes of manufacture or treatment of articles in common use in daily life. Drinker (2) in 1930 defined dusts as solid particles ranging in size from less than 1 micron[5] to about 150 microns; this definition is probably as applicable as can be had insofar as concerns respiration.

Physiologically, there are almost as many different classifications of dust as there are authors on the subject. Richardson (1) suggested the following: (a) Cutting dusts, formed of minute, hard, crystallized particles with sharp, cutting, and pointed edges and composed of iron or steel, stone, sand or glass, dried silicates in earthenware, lime, and pearl; (b) irritant dusts derived from woods, ivory, textile fabrics, fluffs of wool, silk, cotton, flax, hemp, hair, and clay; (c) inorganic poisonous dusts charged with arsenical salts, derived from poisonous chemical compounds used for coloring artistic products or for preserving organic substances, such as furs; (d) soluble saline dusts, organic poisonous dusts thrown off during the making of tobacco into cigars and snuff and carrying with them particles of the dried tobacco plant; (e) obstructive and irritating dusts composed of carbon, fine particles of coal dust, scrapings of carbon or soot, dust of rouge, and flour.

Baskerville (3) in 1912 classified dusts as: (a) Insoluble inorganic dusts, including metals (antimony, arsenic, type metal, brass, bronze, copper, aluminum, iron, steel, lead, manganese, vanadium and ferrovanadium, silver, tin, zinc, and solder) in a state of fine division (dusts, atomized metals, metallic powders); flue dusts; various ore dusts (iron ore); silica; sand, emery, flint, glass powders; carbon graphite, diamond, coal, soot; brick dust, marble, granite, cement, terra cotta; lime, gypsum, plaster, meerschaum; phosphates; and guano. (b) Soluble inorganic dusts, including substances likely to be swallowed and absorbed, such as metal particles, including lead, brass, copper, zinc, arsenic, mercury, and silver, as well as soluble inorganic salts. (c) Organic dusts, comprising such widely varying materials as sawdust, fur, skins, feathers, broom straw, grains, flours, jute, flax, hemp, cotton, wool, carpet dust, street sweepings, tobacco-box dust, hides and leather, felts, rags, paper, and horsehair.

In 1918 Hoffman (4) considered the following classification to be in strict accord with the facts as they were known and understood at that time:

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4 Numbers in parentheses refer to bibliography at end of circular.
5 A micron is 1/1,000 of a millimeter or approximately 1/25,000 of an inch.

(a) Inorganic dusts, including metallic dust, mineral dust, and dusts of the mineral industries; (b) organic and miscellaneous dusts, including vegetable-fiber dust, animal and mixed-fiber dust, organic dust, and mixed organic and inorganic (public) dusts.

Thompson (5) classified dusts as (a) insoluble inorganic dusts (irritating the respiratory passages), as flint, silica, sand, carbon (coal, soot), brick dust, marble, granite, terra cotta, cement, asphalt, enamel, glass, quartz, lime (gypsum, plaster), meerschaum, phosphate (fertilizers), guano, emery, diamond dust, metal filings (lead, brass, iron, steel, etc.), pumice, and ashes; (b) soluble inorganic dusts (liable to be swallowed and absorbed), as soluble arsenic, mercury, lead and silver compounds, metal filings of lead, brass, and zinc; (c) organic dusts and fibers arising from handling or manufacture of wood, bone, and shell, from fur, skins, hides and leather, feathers, brooms and straw, flour and grain, jute, flax (linen), hemp, cotton, wool (worsted, etc.), tobacco, felt, carpets, rags and paper, horsehair, and street sweepings.

Heim de Balsac and Agasse-Lafont (6) suggested the following classification: (a) Active dusts, which are immediately disseminated and radiate beyond their point of application; toxic dusts (lead, arsenic, and mercury); caustic dusts, chromates, etc.; infectious dusts. (b) Inert dusts, soft flexible felting dusts (wool, cotton, and leathers); hard, troublesome, wounding dusts (ligneous, metallic, stone, and coal dusts).

Schürmann (7) differentiated dust, according to origin, into animal, plant, and mineral dust and dust from the artifacts. Animal dust is evolved with the working of ivory, horn, whalebone, bones, mother-of-pearl, hides, leather, bristles, sheep's wool, hair (horse, rabbit, and cow), and feathers; plant dust has its origin in industries working with grain, medical powders, spices, cotton, hemp, jute, flax, tobacco, wood, thick-shelled nuts, bark of plants (tanning industry), rags, shoddy, and paper; mineral dust is formed in the working of hard coal, marble, and other limestones and in connection with clay and porcelain industries, also pumice, sandstone, granite, and slates; dust from artifacts is found in the glass, glazing, enameling, tile, cement, Thomas slag, celluloid, iron, steel, bronze, galalith, and lead-alloy industries and in the chemical (especially dye) industry. He defined mixed dust as a mixture of polishing materials and the fragments of the object being polished.

According to Drinker (2) all these classifications are without much practical importance, since in daily practice in industry the harmful effect is exercised more frequently by dusts mostly of mixed origin. Besides, what is most important is the physical and chemical constitution of the dusts and consequently their action on the system. An effort has been made to group under the heading "inert" a certain number of dusts; the number, however, is becoming more and more reduced since certain dusts, such as talc and asbestos, until recently considered as inert nevertheless have caused serious organic lesions among certain classes of workers. The majority of experts admit that the so-called "inert" dusts are not really inert when

considered from the pathogenic point of view. Although at the outset they are not harmful and even when present in the workroom in large quantities some of them cause only transitory discomfort (sneezing, watering of the eyes, cough), it is certain that as the organic reactions diminish and the system seems to have recovered from the effects, they nevertheless finally attack it in a subtle manner, sometimes even seriously. The mucous membrane of the nose, the conjunctiva, and first the upper and subsequently the lower respiratory passages, the teeth, the skin, and often the digestive tract are subjected to the harmful action of these dusts.

CHAPTER 2. SOURCES OF EXPOSURE TO DUST

The prehistoric man who originated the trade of making stone implements probably started the first industrial hazard, the extent and severity of which the medical profession, as well as the industries concerned, has begun to realize only recently. In fact, dust as a factor in the causation of disease had not received much attention before 1900. At the site of one of the Swiss lake dwellings where flint implements were found, although the flint must have come from a distance (probably from the South of France) the chippings of material were in such profusion as to imply that the implements were manufactured on the spot. In other words, a prehistoric flint-knapping factory was probably located there (8). Some of the persons who prepared these implements no doubt suffered from respiratory diseases. According to Collis (9) the flint-knappers of Brandon, the lineal occupational representatives of this oldest of industries, who still use tools similar in shape to the deerhorn picks of their prehistoric ancestors, suffer a terrible mortality from phthisis induced by flint dust generated in their work. The work is carried on in small workshops at the back of cottages in the rural district bordering Norfolk and Suffolk, where large flints or potstones are found; the district has been known from remote antiquity for the manufacture of arrowheads and other prehistoric implements, tinder boxes, and in later years flints for flintlock guns.

Dusts of various kinds are carried in the atmosphere in all parts of the world, and the inhalation of these dusts over periods of years inevitably produce changes in the lungs, as for example the pigmented lung of the city dweller (10). Another example of the general exposure to dusts is given in the report by Soper (11), published in 1906, on the air and dust in the 21-mile subway of the Interborough Rapid Transit Railroad of New York City. Chemical analysis of the dust underground showed that it contained 61.30 percent of iron, nearly all of which was in the metallic state, 21.94 percent of organic matter of vegetable and animal origin, 15.58 percent of silica and other matters insoluble in acid, and 1.18 percent of oil. There were on the average 61.6 mg of dust in 1,000 cubic feet of air; the maximum weight was 204 mg. The dust in the air of the subway was 11 to 800 percent heavier than that in the street air. Although some of this dust was carried in from the streets, much of it was of underground origin from the gradual wear and tear of the wood, cement, and other materials used in construction of the subway and also from the operation of the trains, for the largest percentage was iron dust from the grinding action of the powerful brakes on the cars. The loss of weight in the brake-shoes alone was estimated as about 1 ton per mile of track per month, and when the loss from the wheels and the railway track is added to this the origin of the metallic dust is explained. The men had not been employed underground long enough at that time to show the effect on the health of inhalation of the dust. Although no serious disease was found among them many suffered from inflammatory affections of the nose, throat, and windpipe and also from "dry pleurisy" unaccompanied by pain. More than 20,000 workmen are said to be engaged in dusty occupations in New York City alone (11).

Hoffman (4) prepared an occupational grouping to emphasize in a general way the principal dust hazards in 118 occupations or groups of employment, which he said was in strict accord with the facts as they were known and understood at that time (1918). Under the heading "organic and miscellaneous dusts" he listed 65 occupations; under the heading "inorganic dusts" he listed 52 occupations.

He gave the number of persons employed in the dusty trades, according to the United States census for 1910, as 3,928,978; of these 1,667,181 were listed as employed in occupations exposed to metallic and mineral dust and dust in the mineral industries. He considered that quantitatively the most important kind of metallic dust, as met under typical industrial conditions, is the dust of iron and steel, which, however, is generally more or less intermixed with dust of other metallic or mineral substances. Mineral dust exposure is most common in the stone industry, among potters, in cement manufacture, and in mining.

In a paper on the extent and severity of the health hazard from dust in the mines and allied industries in the United States van Siclen (12) gives the following estimates, based on the 1929 decennial Federal Census, of the number of men exposed to dust hazard in various types of mining and industries working in metals and minerals:

	Total exposed
Metal mining	62,268
Nonmetallics mining, omitting tunnel and foundation excavations	23,665
Bituminous-coal mining, underground	450,513
Bituminous-coal mining, open pit	8,219
Anthracite mining, underground	143,063
Anthracite mining, independent washeries	269
Smelting, nonferrous plants	13,166
Smelting, ferrous plants	24,960
Cement plants	53,368
Abrasive industry	3,873
Asbestos products	8,092
Clay products	93,336
Cutlery	14,991
Glass manufacture	67,527
Granite, slate, marble, and other stone products	28,715
Hones, whetstones, and similar products	174
Iron and steel	39,697
Mineral fertilizers	20,926
Minerals and earths, ground	1,679
Nonferrous metal alloys and products	79,183
Pottery, including porcelainware	33,409
Sand-lime brick	566

In his conclusion he states:

> No totaling of the number of workmen exposed to the dust hazard in the mining and allied industries in the United States, as estimated in the preceding pages, has been undertaken; first, because the estimated figures themselves are subject to revision after more detailed study of the mineral industries and manufactures, and second, because the degree of the dust hazard varies with the several industries, with the manifold occupations in each industry, and between similar positions in different plants of the same industry. A lump-sum total would therefore have no real meaning. The separate totals, however, are sufficient to indicate the wide extent of this kind of hazard.

In Great Britain in 1930 some 35,000 workers, excluding coal miners, were employed in the refractories industry, tin mining, pottery industry, metal grinding, sandstone-working, sand-blasting, and other trades in which dust is a prominent feature (10). In 1931, 877,141 men were employed in the coal mines of Great Britain. In 1930, 287,540 men were employed in the mines of France, 155,397 in the mines of Belgium, and 400,654 in the mines of Prussia (excluding lignite mines) (13). About 300,000 men are employed in the mines of South Africa (14). Probably 150,000 persons are employed in the quarrying, cement, and pottery and stoneware industries of Germany (15).

The above figures on number of employees in the dusty trades are given merely to indicate the possible exposure to the dust hazard and, of course, are in no way complete figures of the actual number subjected to the hazard. According to Lanza (16) the prevalence of silicosis has been estimated carefully in a few instances, but the rates so obtained cannot be applied generally because industrial conditions vary so widely. However, it is apparent that silicosis is a widespread industrial hazard, is probably increasing, and affects appreciably the death rate among industrial workers exposed.

Only dusts encountered in the mining and allied industries and the diseases caused by them will be considered in this paper.

CHAPTER 3. PHYSIOLOGICAL EFFECTS OF BREATHING DUST

Historical Résumé

Probably the oldest published data regarding the harmfulness of exposure to dust is the statement in Pliny's Natural History (17) that -

> Minimum refiners in the factory envelop their faces with loose bladders, which enable them to see without inhaling the fatal dust.

Hippocrates (18), who was born about 460 B.C., called attention to the difficult breathing of the metal digger. Celsus, a Roman medical writer who lived in the first century, states:

> By far the most terrible form of emaciation is that which the Greeks call phthisis. It spreads to the lungs. On top of this ulceration occurs and a slow fever which at times disappears and at other times reappears.

In quoting the above Mavrogordato (19) says that one may assume that when early writers discussed dust phthisis the disease they had in mind was of the nature mentioned by Celsus.

In 1551 Amatus Lusitanus (7) reported that most workers occupied with the preparation of gypsum and lime died of lung phthisis.

Agricola (20) in his De Re Metallica, published in 1556, described mining as "a perilous occupation to pursue because the miners are sometimes killed by the pestilential air which they breathe; sometimes their lungs rot away."

He also states (20):

> Some mines are very dry and the constant dust enters the blood and lungs, producing the difficulty of breathing the Greeks call asthma. When the dust is corrosive it ulcerates the lungs and produces consumption; hence it is that in the Carpathian Mountains there are women who have married seven husbands, all of whom this dreadful disease has brought to an early grave.

According to Mavrogordato (19) we learn from Georgius Agricola that in the sixteenth century it was known that permanent injury to the lungs resulted from exposure to certain kinds of dust but not to all kinds. Two kinds of injurious dusts were acknowledged - a noncorrosive and a corrosive type. Each of these classes was associated with a different kind of lung change - "simple" and "infective" silicosis, respectively, described in the 1916 General Report of the Miners' Phthisis Prevention Committee of South Africa.

Paracelsus (21), a Swiss alchemist and physician, in his book on miners' phthisis and other miners' diseases described especially the chronic lung troubles of miners as "lung consumption", "asthma", and "dyspnea." He was the first to list briefly the occupational diseases of miners and smelters as well as the first in world literature to prepare a monograph on industrial medicine (21). From 1531 to 1534 Paracelsus revisited the mines and smelters of Schwaz in the Tyrol where he had worked as a laborer between 1510 and 1520 and wrote his book, which was published in 1567 after his death. He found that -

> Miners in metal mines, when they are occupied in digging, smelting, and washing gold, silver, salt, alum, sulphur, lead, copper, zinc, iron, and quicksilver in the refining of vitriol, suffer from various disturbances of the lungs, stomach, and intestines; they are then said to have "miners' diseases." However, there is nothing found in the old writers in regard to these diseases.

His theory was that lung diseases contracted aboveground depended upon climatic conditions, which were influenced by the rays of the stars. Similarly, pulmonary disease of miners underground was caused by mineral rays. However, he philosophically reminded his readers that -

> We need metals and, therefore, we must risk life and health for them, since everywhere in nature good and evil lie together. As the crocodile distresses and kills men by his breath, likewise also the vapors (fine dust?) of such metals kill us. * * *. The organism must be prevented from coming in contact with the metal emanations; for if the organism is once injured there is no cure.

A present-day author expressed a similar idea when he said (22) that the increasing interest in the subject is a recognition of the condition of pneumoconiosis as a more or less necessary risk of commercial development in the progress of civilization in recent years.

It is said that the early death of Paracelsus was due to injuries to health received during his activities in the mining and metallurgical industries.

According to Schürmann (7), Pansa, in 1614, was the first to discuss in detail lung diseases of miners and the asthma of grain measurers. In 1649 Diemerbroek (23) is said to have made the first section of a stonecutter's lung which, in a case of fatal asthma, revealed "lung vesicles completely clogged with fine dust"; he is quoted by Ramazzini (24) as finding such heaps of sand that in running the knife through the pulmonary vesicles he thought he was cutting some sandy body.

In 1652 Ursinus (25) wrote of the lung disease that attacked especially the miner but also the smelter. He divided lung diseases into two classes - one was caused by poison, and the other was not. The principal symptoms he described were coughing and shortness of breath. Etiology was a question

of breathing dust, catching cold, fatigue, injury, and the like. He said the lung disease due to "poison" was not so clear and was unknown before Paracelsus.

In his book published in 1656 Stochhausen (26) defined miners phthisis as "difficult breathing, chest asthma with disagreeable hard cough and considerable hoarseness, which effects generally degenerate into fatal consumption." He attributed these symptoms to metallic vapors, dust, and meteorological conditions, from which miners suffer more or less and call "miners' consumption" because the affliction arises especially in connection with mining. The actual cause he attributed to "especially thick, lowering clouds and mine dampness, watery humidity, all sorts of vapors of earth and metal, various fumes and smoke, different dusts and dirt." He also said that much dust arose from grinding so that workers were forced to cover nose and mouth with cloths.

In 1690 Löhneiss (27), referring to miners, gave the morbid sequence of events as follows:

> The dust and stones fall upon the lungs, the men have lung disease, breathe with difficulty, and at last take consumption.

Ramazzini (7) was the first to recognize the social significance of industrial diseases from chemical substances. In his book published in 1700 he mentioned the harmful effect of dust on the respiratory organs. For information he went to the workers in the occupations, entered the mines, ascended the mine shafts, and collected the experiences of his occupational colleagues. His book was based on a study lasting more than 40 years.

Referring to the fact that flint dust had long been recognized in England as injurious Collis (28) said that a patent for grinding flints by a wet method had been granted in 1713 to Thomas Benson, of Newcastle-under-Lyme; previous to this time flints were pounded dry,

> which process proved very destructive to mankind insomuch that any person, ever so healthful and strong, working in that business, cannot possibly survive over 2 years, occasioned by the dust sucked into his body by the air he breathes.

In 1783 Hoffman (29) stated that breathing metal fumes and vapors, as well as dust, caused the disease picture of "miners' phthisis."

According to Henkel (30) (1745) the external causes or occasion of miners' phthisis were dust from stones and metals, lack of air, bad air, or bad fumes or vapors.

In 1770 Scheffler (31) wrote that the description of miners' phthisis given by previous medical men was insufficient. His conception of it was a

> chronic slow fever with hardening of the glands and obstruction of the lungs with a lack of elaboration, secretion, nutrition, and apposition which through the arsenical or other dusts dries out the soft lymph of the glands in the lungs and air passages.

The symptoms given by him were slight fever, loss of appetite, cough, shortness of breath, and swollen feet, the patients finally becoming bedfast and showing great weakness, irregular pulse, sleeplessness, dry skin, usually constant fever, often bloody sputum, hemorrhage, sweating, and diarrhea until death claimed them.

In 1780 Ackerman (32) called miners' phthisis without doubt the most "frequent and specific" mineworkers' disease and said that physicians did not agree regarding the true definition of this disease.

As the result of a special inquiry into the prevalence of dust phthisis Allison (33) found that rarely did a mason, regularly employed in hewing stones in Edinburgh, live free from phthisical symptoms to the age of 50. According to Mavrogordato (20), Allison, a professor of medicine at Edinburgh, established the association between dust phthisis and tuberculosis, that is, between dust phthisis and true phthisis. It was not dust per se that was responsible for the "ulceratio" of Celsus but a secondary complication. The corrosive dust of sixteenth-century Agricola and eighteenth-century Ramazzini became the "tuberculosis" of Allison. Allison like Laennec knew of the anatomical tubercle but not of the tubercle bacillus.

Hugh Miller (34), the famous writer, geologist, and stonemason in telling of his own narrow escape wrote:

> The dust of the stone which I had been hewing for the last 2 years had begun to affect my lungs, as they had been affected in the last autumn of my apprenticeship, but much more severely; and I was too palpably sinking in flesh and strength to render it safe for me to encounter the consequences of another season of hard work as a stonecutter. From the stage of the malady at which I had already arrived, poor workmen, unable to do what I did, throw themselves loose from their employment, and sink in 6 or 8 months into the grave - some at an earlier, some at a later period of life; but so general is the affection that few of our Edinburgh stonecutters pass their fortieth year unscathed, and not 1 out of every 50 of their number ever reaches his forty-fifth year.

Thackrah (35), however, claimed that such generalization was not justified and stated that "dust of every kind irritates but not in an equal degree." He recognized that masons inhaling particles of sand and dust which arise from chipping stone were short-lived, generally dying before they attained the age of 40. Thackrah also dwelt on the prevalence of phthisis among the metal grinders of Sheffield and quoted Knight's opinion that fork grinding ought to be confined to criminals. A few years later Holland (36) portrayed the conditions of fork grinders -

a picture of wretchedness which has no parallel in the annals of any country, or in the records of any trade. Fiction can add no color or touches to a picture like this. Truth transcends the gaudy embellishments of imagination. The distempered fancy has here no room to exercise her powers.

Incidence of Dust Diseases

According to Greenburg (37) data on prevalence of occupational disease in different countries and at different periods of time must be interpreted with the greatest caution, because industrial processes differ so widely and change so frequently. To be conclusive such data should be available in the form of actual death rates, based on knowledge of the population exposed as well as on the number of deaths occurring, and properly corrected for the age distribution of the group involved.

A brief summary of available information on the incidence of dust diseases in some of the principal countries of the world follows.

Great Britain

In 1862 Royal Commissioners were appointed in England (9) to inquire into the health of men employed in metalliferous mines. Notwithstanding the evidence of several witnesses, particularly the miners themselves, that dust was far worse than anything else with which they had to contend, the commissioners concluded on practically unanimous medical opinion that the influence of dust was subsidiary to the many other adverse conditions of ventilation, exposure to fumes of explosives, and variations of temperature which at that time were prevalent in the mining industry. Collis (9) said this conclusion was unfortunate, as the prevalence of phthisis in certain industries was attributed to imperfect hygienic conditions rather than to dust inhalation, a point then in dispute.

In 1902 a departmental committee (9), of which Haldane was a member, was appointed to reinvestigate the cause of the still persistently high phthisis mortality among Cornish tin miners. This committee decided that -

> So far as the Cornish miners are concerned it seems evident enough that stone dust which they inhale produces permanent injury of the lungs - gradually in the case of ordinary miners, and rapidly in the case of machine drillmen - and that this injury, while it is apparently capable of gradually producing by itself great impairment of the respiratory functions, and indirectly of the general health, also predisposes enormously to tuberculosis of the lungs, so that a large proportion of miners die from tubercular phthisis. That the primary injury to the lungs is due solely to inhalation of stone dust would seem to be practically certain.

From February 1, 1919, when the first scheme of compensation for silicosis was made for the refractories industry, until the end of 1928 compensation awards were made in England in 423 cases, including 121 deaths

(38). During the period 1921-23, 328 deaths were recorded for England and Wales under the generic title "chronic interstitial pneumonia", which included such diseases as fibroid phthisis, fibrosis of the lungs, silicosis, and miners' phthisis, when returned as nontuberculous (39). In 1926 the question was asked in Parliament (40) as to the number of men not affected by the Silicosis Act but when examined by officers of the Home Office during the preceding 5 years had been found suffering from the disease. The reply was that no routine examination of workers had been made by the medical inspectors of factories except sample examinations in connection with special inquiries into the grinding and other industries. Of 1,106 workers employed in processes involving silica dust so examined 556 were found to be affected by fibrosis of the lungs; 528 of these men were employed in the grinding industries and 28 at steelworks.

A memorandum on industrial silicosis and asbestosis issued by the Home Office in July 1932 (41) stated:

> The incidence of silicosis continues to be serious and widespread, as is shown by the following figures of cases in which compensation has been paid under the special schemes made under section 47 of the Workmen's Compensation Act, 1925. During the last 3 years there have been 80 cases, including 30 deaths, amongst workmen employed in ganister mines and silica brickworks; 179 cases, including 25 deaths, in the getting and manipulation of sandstone at quarries or on premises worked in conjunction therewith; 322 cases, including 87 deaths, in the pottery industry; 81 cases, including 32 deaths, in the metal industries, including metal grinding and sandblasting; and 91 cases, including 20 deaths, in coal mines.

According to Stewart (42) in districts of Lancashire County, where the industry of coal mining predominates (40 percent of the occupied males being engaged in mining), the male death rate from pulmonary tuberculosis is higher than the corresponding rate for the whole administrative county.

Sladden (43) stated that during the 4 years 1925-28 he had examined the bodies of 20 coal miners; 1 had advanced silicosis and 7 other slighter degrees of the condition. Since 1929, 63 examinations were made, 27 of which showed definite and serious degrees of silicosis and 16 others slighter degrees. In this connection Haldane (43) said he preferred the more general term "pneumoconiosis" for these cases. Among anthracite miners he found the deaths of 30 of 83 bodies examined definitely attributable to pneumoconiosis. He stated that in all cases, whether anthracite or nonanthracite, a high percentage of silica was the outstanding feature in chemical analyses of the lungs.

The 1930 report of the chief inspector of factories and workshops (44) states:

> By a recent arrangement the factory-inspection service receives copies of all death certificates in which death resulted from pulmonary disease involving fibrosis of the lungs. Of 700 such certificates

received in 1930, 241 gave silicosis as the cause of death and in the great majority of cases it was found that the previous occupation of the persons concerned was one in which there was recognized exposure to silica dust.

The industries furnishing the greatest number of such cases were the pottery trade, 52; sandstone, 49; coal mining, 39; sand-blasting, 10; tin mining, 10; and other industries, 90. The report also said that recent investigations of the effects of exposure to asbestos dust had resulted in the adoption of measures to control dust in the textile branch of the asbestos industry. Data regarding 20 fatal cases of asbestosis without tuberculosis show a serious hazard in continued exposure to heavy concentrations of asbestos dust.

In 1931 Wood and Gloyne (45) were prompted by the recent discovery that asbestos workers are often the victims of occupational disease to determine whether pulmonary asbestosis also paves the way for a tuberculous invasion of the lungs or aggravates an existing infection. They studied 57 cases of pulmonary asbestosis, including 18 males and 39 females, 8 of whom were young girls from 18 to 21 years old; 12 of the 57 cases showed evidence of pulmonary tuberculosis, 4 of the 12 died, and on post-mortem examination evidence of obsolescent tuberculosis was found in 2 and of active tuberculosis in 2.

Merewether (46) found 4 active cases of tuberculosis and 33 inactive on examination of 374 asbestos operatives while at work. According to Sparks (47) 2,000 workers in England are exposed to asbestos dust.

An inquiry by Sutherland and Bryson (48) on the occurrence of silicosis among sandstone workers in England since February 1, 1929, under the Workmen's Compensation Act of 1925 disclosed that 1 of every 4 men at work appeared to have "masons' disease." As only men at work were examined cases as far advanced as third stage and many in second stage, not being at work, were not included in the survey.

The outstanding feature of an investigation by Ferguson (49) of the occurrence of silicosis among sandstone workers in Scotland and the North of England was the high degree of pulmonary morbidity existing throughout the industry. Of 1,000 working people examined 433 showed clinical evidence of pulmonary fibrosis. Radiological examination of all the workers showing clinical evidence of fibrosis was impracticable but doubtless would have disclosed other cases of silicosis; most of the cases X-rayed by Ferguson were those showing the severest fibrosis and those which gave the most reason for suspecting the presence of silicosis. One hundred and seventy-three of these workers showing clinical evidence of pulmonary fibrosis were X-rayed; 97 showed first-stage and 12 second-stage silicosis (advanced, nodules coalescent).

The report of the chief inspector of factories and workshops in Great Britain for 1932 (50) considers particularly 42 deaths from asbestosis or asbestosis with tuberculosis and 281 deaths from silicosis or silicosis with tuberculosis distributed among the industries as follows: Pottery, 147; sandstone, 60; grinding materials, 30; sand-blasting, 23; scouring powder, 5; miscellaneous, 16.

Under the heading "Parliamentary Intelligence" the Colliery Guardian (51) on August 4, 1933, published the following:

> In the House of Commons on Friday, on the motion for the summer adjournment, Mr. R. Davies introduced a discussion on the annual report of the Chief Inspector of Factories, in the course of which Mr. Tinker raised a number of questions relating to industrial diseases and the solvency of employers, as a remedy for which he demanded a system of compulsory insurance. Mr. R. T. Evans suggested that the bronchial diseases particularly affecting miners should be placed in a separate category and dealt with by the Mines Department under a new order. Mr. E. Williams complained that scores of men had died from silicosis in South Wales, whose dependents had not received a farthing of compensation and that there were also scores who were dying but were not receiving compensation after having worked for years in hard ground, because the rock did not contain a certain amount of silica. He also urged that anthracosis should be scheduled as an industrial disease.

On February 16, 1934, the Colliery Guardian (52) published a statement from the Home Office that since June 1, 1931, when the coal-mining industry first came within the scope of the General Medical Board under the Silicosis Compensation Scheme, 432 men in the industry had been certified by the board as disabled or having died from silicosis or from silicosis accompanied by tuberculosis and that 385 of these cases occurred in the South Wales coal field. Earlier comparable figures were not available.

On March 16, 1934, The Iron and Coal Trades Review (53) quoted the following statement by Prof. J. S. Haldane from the British Medical Journal:

> Cases of silicosis in the sense normally accepted end nearly always in death from phthisis, and if there were actually a large number of cases of real silicosis in this sense among South Wales colliers, their phthisis death rate would be considerably increased above the normal figure. There seems to be no sound reason for believing that many more cases of real silicosis occur among South Wales colliers than among other colliers, and I think the widespread alarm produced in the South Wales colliery district by the numerous certified cases of silicosis has no substantial basis so far as silicosis is concerned.

However, Harper (54), a radiologist practicing in the South Wales coal field, in a letter to the British Medical Journal published in May 1934 said that when the full facts were known there was little mystery in the many cases of silicosis found in that part of South Wales. Deductions are made from the pay of the coal miners at the colliery offices in behalf of the medical men in the district; therefore the workmen can have roentgenological examinations if the family doctor is doubtful of their condition, and silicosis at present is the fashionable disease in the area. Harper (54) states that it is probably safe to say that more colliery workmen have been X-rayed in this area than in any other part of the coal field; hence more cases of silicosis have been found than in other areas where no such

examinations are made, which partly explains why there are more known cases here. In fact, Harper said, there are more cases of silicosis than have been either examined or passed by the board because some refused to be examined, preferring to continue at work regardless of the cost to their health rather than be retired by compulsion with partial compensation of about £1 a week to meet the necessities of life and no further hope of employment. He quoted Kettle as saying that nearly all the specimens sent to the board from this area were those of infective silicosis, and the infecting organism was most commonly the tubercle bacillus. Harper considered this statement much more reliable than any returns of the Registrar General. Therefore there would seem to be no difference between the silicosis in South Wales and the commonly accepted type, and he could find no roentgenological difference between cases of silicosis in South Wales and cases he had seen in the Belgian coal fields.

Germany

In Germany industrial pathology was developed at the beginning of the nineteenth century simultaneously with the upward trend of German industry (7). In 1781 Tissot (55) graphically illustrated the health hazards encountered by stonemasons; he stated that in one place where the people formerly had been engaged in felling trees and in carving they were the "handsomest, strongest, and healthiest of persons" but for 25 years - since the inhabitants had turned to stonecutting - there had been in that region the most lingering diseases. In 1804 and 1812 Goetzinger (56) in describing the mountainous part of Saxony said that the fine dust and drink brought the stonecutter to an early death.

According to Schürmann (7) only a few works have been published on the harmful effects of iron and steel dust to which the metal polisher is exposed, in spite of the fact that the works of Paracelsus, Ramazzini, and others were known in Germany, Ramazzini's work being the sole textbook in the field of occupational disease used in Germany up to the middle of the nineteenth century. In contrast to the English reports on the health picture of the Sheffield polishers, Hauer (57) in 1832 reported conditions among German polishers as not unfavorable to health. Nasse (58) was the first to report in regard to polishers' disease; he wrote that the grinding workers lasted only 12 years and recommended respiratory protection for them. The first known German publication on the harmful effects of dust on polishers was issued by Pappenheim (59) in 1860. In 1866 Zenker (60) determined iron oxide in a lung and called the disease caused thereby "siderosis." He designated the diseases of the lungs caused by dusts as "pneumonoconiosis." In a book by Schlockow (61) on the care of health and medical statistics in Prussian mines, published in 1881, the statement is made that of 942 miners examined by Seltmann 37.7 percent had emphysema of the lungs.

Only 5 roentgenologically normal pictures were found among 25 sandblasters examined by Lochtkemper (62) in 1930; the remaining 20 (80 percent) revealed various stages of silicosis. Thiele (63) found that 28 percent of porcelain workers examined by him were affected by pneumoconiosis; Holzmann

and Harms determined roentgenologically the presence of pneumoconiosis in 75.6 percent of 41 selected porcelain workers; and Koelsch found 58 percent of 19 workers affected. Böhme (64) determined pneumoconiosis in 28 percent of 184 coal cutters who had worked more than 10 years underground and in 66 percent of hard-rock miners; in another investigation he determined by X-ray examination that 36.2 percent of 69 hard-rock miners had pneumoconiosis and by clinical examination 17.3 percent. Komissaruk (65) examined clinically and roentgenologically 40 foundryworkers who had worked in dusty industries for more than 10 years; 4 definitely had pneumoconiosis, 5 were doubtful, and 3 were borderline cases. In 23 cases the X-ray revealed old inactive pulmonary tuberculosis, but no tubercle bacilli were found in the sputum.

In 1932 Lochtkemper and Teleky (66) published the results of an extensive study on dust which covered working conditions and health of workers in many different dusty trades. However, the number of workers examined in each group was usually too small for definite conclusions. Examination of 22 women employed in a scouring-powder factory in 1930 revealed that all but 3 were affected by silicosis in varying degree, 6 being in stage 3. Examination of 7 workers in a sand and cement plant resulted in the diagnosis of 1 case of silicosis in the first stage and 2 in the third; the others showed no indication of silicosis or only slight pneumoconiosis which the authors classify as "silicosis 0-I." Inquiry among workers and physicians of the region revealed that 4 had died and 2 were still ill of tuberculosis. Six of 7 shell limestone cutters examined were diagnosed as having pneumoconiosis 0-I and 1 silicosis 0-I. Of 18 graywacke workers examined 3 were diagnosed as negative, 4 as having silicosis 0-I, 4 silicosis I, 3 silicosis II, 1 silicosis I-II, 1 silicosis III, and 2 silicosis II with tuberculosis.

From an examination of the statistics of a large sick benefit association Koelsch and Kaestle (67) found the illness frequency, especially for tuberculosis and diseases of the respiratory organs, less for the quarry and shell limestone workers than for the other members of the association, but the mortality rates apparently were greater for the stone workers (0.35 percent) than for the others (0.21 percent). These investigators examined 82 persons who had worked in shell limestone only; 14 had more or less definite signs of dust lung, but it differed in appearance from the silicosis of the sandstone worker. They concluded from these examinations that under certain conditions limestone also can cause changes in the lungs within the meaning of dust lung if it can have a correspondingly long action. Dust lung was more frequent and more pronounced among those who had worked in limestone and sandstone, the more so the closer the work in sandstone had followed upon that in shell limestone.

According to Landau (68), the cleaning of metallic castings presents great health hazards to the men engaged in the work. Among those examined 69 percent had pneumoconiosis and 8 percent tuberculosis. Work with steel seemed to be much more dangerous than with cast iron, probably because compressed-air tools were used in cleaning the steel castings which were cast in a mold of sand very rich in silica.

Australia

In 1902 while a system of sewers was being dug in Sydney, Australia, a Sewer Works Ventilation Board (69) was appointed to inquire into the working conditions and to recommend means of improvement whereby the work could be rendered less hazardous. The board found that -

> For many years past miners employed in this class of work (tunnelling) suffered acutely from a disease which was for a long time known by the rather misleading term "sewer disease", but as the complaint became more widely known it was strongly suspected that dust was the chief cause of the mischief.

The board blamed the fumes of explosives and the expired air from the lungs of the miners in imperfectly ventilated tunnels as causes contributory to the high mortality but stated that the dust from hammering, drilling, and the use of the pickax was probably the sole cause of the disease once known as "sewer disease."

In 1912 Armstrong (70) investigated a reported epidemic of pneumonia at Broken Hill and found that the death rate from pneumonia among underground miners in that locality during 1910-12 was 6.5 per 1,000, or nearly 4 times as great as that for all males in New South Wales. In 1914 a Royal Commission was appointed to inquire into the mining industry at Broken Hill. With regard to industrial diseases this commission stated that pneumoconiosis and plumbism were among the risks of a miner's calling, while other diseases - for example, pneumonia - were added risks but not strictly industrial because they affected others than miners. From unanimous medical testimony the commission concluded (70) that pneumonia was more prevalent, severe, and fatal among miners in Broken Hill than among any other class in the State. Although attributing the prime cause to sudden changes in temperature the commission advanced the opinion that dust inhalation in any form would predispose to disease. It also expressed the opinion that pneumoconiosis was virtually unknown at Broken Hill and blamed mining in other States for such cases as had been noted. Tuberculosis, however, was a disease to which the miners at Broken Hill, as elsewhere, were peculiarly subject, and the presence of tuberculous patients in a mine was considered particularly dangerous.

In 1919 the Technical Commission (70), constituted to examine the miners at Broken Hill, for the first time in Australia used the X-ray as a means of diagnosis of silicosis as an occupational disease. Of 4,337 mine employees examined 193 were diagnosed as having pneumoconiosis - 90 in the first stage, 44 in the second, and 59 complicated with tuberculosis; 39 cases were definitely diagnosed as suffering from pulmonary tuberculosis only and 26 others were thought to be suffering from uncomplicated pulmonary tuberculosis. Of 2,618 underground men examined in 1922, 266 showed pneumoconiosis - 113 in the first stage, 51 in the second stage, and 102 complicated by tuberculosis; 107 additional men were diagnosed as suffering from tuberculosis only.

In 1922 the New South Wales Board of Trade, in conjunction with the Commonwealth Department of Health (70), investigated clinically and radiologically the prevalence of pulmonary diseases among workers in sandstone and other siliceous rocks in the metropolitan district of Sydney; of 716 men examined 123 were found to be suffering from silicosis. Using the standards set by the Broken Hill Commission, 47 of these were diagnosed as being in the first stage, 38 in the second, and 38 suffering from pneumoconiosis complicated by tuberculosis; 16 were diagnosed as having pulmonary tuberculosis only.

The Workers' Compensation Commission of New South Wales (71) reported on 1,300 of 1,500 workmen examined up to August 23, 1929, as follows: Of 107 stonemasons examined 9 had tuberculosis, 17 were in the various stages of silicosis, and 26 had silicosis with tuberculosis. These men had worked in the industry from 10 to 55 years. Of 29 monumental masons examined 2 had tuberculosis, 1 class A silicosis, and 5 silicosis with tuberculosis; of 37 ballast quarrymen 1 had tuberculosis and 2 marked silicosis; of 80 dimension quarrymen 6 had tuberculosis, 3 early silicosis, 2 marked silicosis, and 16 silicosis with tuberculosis. Of the 377 rock choppers examined 12 had tuberculosis, 25 silicosis, and 10 silicosis with tuberculosis.

In 1931 Moore (71) reported an investigation in New South Wales to determine the incidence of fibrous pneumoconiosis among coal miners; 471 volunteers who had worked at least 10 years underground were examined by the Division of Industrial Hygiene; 199 came from 1 mine, several employees of which had had pulmonary fibrosis; the remaining 277 volunteers were employed in 8 other mines of the district. The percentage of cases of fibrosis for all men examined was 25.9. The percentage of fibrosis among men with coal-mining history only ranged from 22.5 to 25.7 percent; the percentage incidence among men who had worked also in metal mines or quarries as well as in coal mines was 39.7.

In Tasmania in 1928 (69) the various mining centers were visited in turn and men examined clinically and radiologically virtually at the mine head; 65 percent of the mine employees available were examined. Of 314 underground workers 5.9 percent were suffering from uncomplicated silicosis and 2.1 percent from silicosis with tuberculosis. Of all workers examined 1.1 percent were suffering from tuberculosis only - 1.2 percent of the underground and 1 percent of the surface workers.

In 1910 a Royal Commission appointed to report on pulmonary diseases among the miners in the Western Australian gold-mining industry (69) concluded that -

> The miner is more liable to lung disease generally than the average male over 15 years of age. The miner is less long-lived than the average male over 15, partly on account of greater liability to lung diseases.

Tuberculosis of the lungs is on the increase among miners and is twice as prevalent as among males over 15.

Pneumonia among the acute, and bronchitis, asthma, emphysema, and fibrosis of the lungs among the chronic lung diseases are more prevalent among miners than among males over 15.

The principle was laid down that -

Any man suffers from fibrosis to the extent to which he is exposed to the continued inhalation of mineral dust. If there is no dust, there will be no fibrosis, and conversely, the continued inhalation of dust certainly produces fibrosis.

During an investigation (72) in 1925-26 of pulmonary conditions of mine employees in Western Australia 3,039 men were examined at Kalgoorlie and 1,028 at 9 other mining centers throughout the State. Of the 4,067 men examined 798 (19.6 percent) presented definite evidence of pulmonary silicosis and 155 (3.8 percent) had tuberculosis; 12 of the latter group had tuberculosis without silicosis. Of the 1,759 surface workers 6.6 percent had silicosis, 1.5 percent silicosis with tuberculosis, and 0.3 percent tuberculosis alone. The surface workers engaged in dry milling without previous underground experience showed the highest incidence of silicosis - 9.6 percent were affected compared with 2.2 percent of the employees engaged in wet milling without dry-milling experience, and 2.0 percent of those who had had no wet- or dry-milling experience. Of the 2,308 underground workers 23.3 percent had silicosis, 5 percent silicosis with tuberculosis, and 0.3 percent tuberculosis alone. No fewer than 51.5 percent of the workers engaged in developing and 39.2 percent in stoping were affected with silicosis or tuberculosis, in contrast with 8.4 percent of those without stoping or developing experience.

Since 1926 the mine employees in Western Australia have been examined annually by the Commonwealth Department of Health (72). Of 2,290 men previously classed as normal 30 (1.3 percent) were found on reexamination in 1927 to be suffering from uncomplicated silicosis and 13 (0.5 percent) had tuberculosis only; of 491 diagnosed as silicotic 86 (17.5 percent) had silicosis with tuberculosis. In 1928, of 2,822 men classed as normal the previous year, 48 (1.7 percent) had progressed to silicosis only, 11 (0.4 percent) had progressed to silicosis plus tuberculosis, and 3 (0.1 percent) had simple pulmonary tuberculosis; of 425 silicotics 25 (5.9 percent) on reexamination showed signs of tuberculous complication. In 1929, of 2,293 normals reexamined, 100 were diagnosed as silicotic. Silicosis was not found in any case under 40 years of age or with less than 5 years of underground work.

In 1907 a report on miners' phthisis to the Committee of the Bendigo Hospital, Victoria, Australia (69) stated that there was undue mortality among Bendigo miners due to respiratory diseases, notably tuberculosis. The cases examined were classified according to two clinical types - a pure fibrosis of the lungs, nontuberculous in origin, silicosis; and a mixed

type with a tuberculous infection in a fibroid lung. Of 61 men examined in Bendigo in 1928, 9.4 percent of the underground workers were diagnosed as suffering from uncomplicated silicosis and 7.5 percent from silicosis and tuberculosis; 3.3 percent of all workers were found to have tuberculosis only.

Netherlands

In the Netherlands (73) a medical examination of 2,013 stonemasons in 1899 revealed 169 tuberculous cases and 10.8 percent strongly suspected of having tuberculosis. During the period 1891-1900 the death rate among stonemasons for all men between 18 and 50 years of age was greater than in any other occupation. Even such injurious occupations as typesetting, cigar-making, and diamond-cutting showed considerably lower death rates. The death rate in the age group 18-24 years differed little from the average for all occupations; the highest death rate was noted between 36 and 50 years. Of 952 stonemasons dying during 1886-98, 87 percent died of diseases of the respiratory organs. The first general examination of adult stonemasons took place in 1923, the second in 1926, and the third in 1929. In 1923 in nearly half of the cases the X-ray examination gave more information than the physical examination. Of 69 cases in 1929 lung affections were not shown clinically in 19 but were shown in the X-ray examination and in 38 cases both clinically and by X-ray.

As a result of examination of stonemasons who in the course of their lives had worked on certain kinds of stone and others who had worked on more than one kind of stone, Kranenburg (73) reported that of 16 sandstone workers 2 were in the second stage and 5 in the third stage of silicosis after 20 to 30 years' employment in the occupation; of a total of 74 Belgian limestone masons only 5 were in the second stage and none in the third stage after the same number of years' employment in the occupation. Using the third stage as a test, the proportion was more unfavorable among the 90 stonemasons working various kinds of stone including sandstone than among the Belgian limestone workers, although relatively favorable in comparison with the sandstone workers. A striking fact was the large number - 18 - of Belgian limestone workers who showed no affection after 10 to 30 years' employment compared with only 4 stonemasons working on all kinds of stone. Fewer cases of third-stage silicosis were found among Belgian limestone workers after 40 to 60 years' employment or longer than among sandstone workers.

In his general conclusions Kranenburg (73) made the following statement regarding the effects of sandstone and limestone:

> The working of sandstone alone must be regarded as more injurious to the lungs than the working of limestone alone. The working of sandstone alone does not always lead to symptoms of silicosis and, on the other hand, the working of limestone alone (Belgian limestone, marble) does not prevent silicosis in a serious form. The working of sandstone and limestone alternately appears to produce less serious results in the same period than the working of sandstone alone.

Italy

In Italy the first clinical and anatomical observations (74) probably were made by Ramazzini. In 1906 Biondi (75) observed that the greatest damage to the miners in the mines of Sardinia was due to the action of dusts from gangue containing silicates. He also noticed that virtually all coal miners were addicted to coughing and continued to expectorate black sputum even some time after they had quit their occupation. He found minor dust injuries among the Bergamo miners in 1907, perhaps because they labored intermittently in mines and on farms. However, in a few miners, especially the older men, Biondi found cases of pharyngitis and bronchial catarrh, with dark sputum due largely to the black smoke of the candles used, and he observed that acute affections of the respiratory apparatus were more serious and more obstinate in these workers.

In 26 post-mortem examinations of Sadinian miners Frongia (76) in 1908 noted that the cause of death was in most cases an acute infection (pneumonia); he also found among these workers many cases of serious and diffused arteriosclerosis, emphysema, and anthracotic foci, with more or less diffused softening of the tissues and gangrenous foci containing a black brothlike matter - the characteristic finding of black phthisis. On the other hand, he found foci of bronchiectasis due to tuberculous infection in only 5 cases. Eighty-five percent of the fatal cases among these miners therefore were not caused by tuberculous infection.

Pesenti, Rota, and Finzi (77) in 1906 reported on health conditions of workers in lime, cement, and plaster. Pesenti affirmed the high incidence of pneumoconiosis among workers in cement and plaster but did not include proportional statistics. He believed that inhalation of cement dust did not produce tuberculosis and did not favor the progress of the disease. Rota and Finzi found that of 63 deaths among the permanent workers engaged entirely in lime and cement work 28 died before the age of 40 and 11 under 50. The cause of death in 20 of the 63 cases was pulmonary diseases - 9 acute pneumonia, 2 pleuromediastinitis, and 9 tuberculosis. Rota and Finzi stated that there was no truth in the statement that workers in limekilns enjoyed a certain immunity from tuberculosis. On the contrary, they found that the greatest toll to this disease was paid by kiln workers. For example, 9 of 35 deaths of such workers were due to tuberculosis. Physical examination of 218 factory workers revealed 122 cases of harsh respiration in the upper respiratory passages, due certainly, they asserted, to an incipient pneumoconiosis or infiltration of dust into the peribronchial lymphatic channels. Harsh respiration was found more frequently in those employed for a long time, especially those who had worked 10 to 12 years; it was present in 52 of 128 kiln workers, 18 of 26 workers transporting stone, 43 of 50 crushing-machine operators, baggers, and porters of sacks. Many workers were also emphysematous.

Bianchi (78) made a careful clinical and radiological examination of 250 workers employed in more or less closed workrooms, as sculptors, rough hewers, modelers, and workers in grinding rooms. After excluding all cases of suspected syphilis and other chronic lesions, they studied 73 workers in marble

who had no inherited disease or previous disease history and were free from definite or suspected symptoms of affections of the respiratory passages which might come under the category of common infections. X-ray examination revealed diffuse nodes of thickened tissue spread over almost the entire respiratory surface. In these cases he could determine only a slight percentage (20 percent) of functional alterations with symptoms of chronic bronchitis and pulmonary emphysema.

As the result of a radiographic and clinical examination of 105 Carrara marble workers employed in marble grinding and of other workers such as sculptors, rough hewers, sawyers, and polishers Turano (79) made the following statement:

> The changes met with among Carrara marble workers may be classed in the initial stage of pneumoconiosis, that is to say, comprising the least serious forms of the disease, such as the very marked reinforcement of the pulmonary outline, due as demonstrated by personal observations, to the processes of arteritis and lymphangitis, and in certain cases equally to conditions of emphysema usually present among those workers.
>
> I have also found frequent pleuritic changes which can be related to inhalation of marble dust, but never lesions of the pulmonary parenchyma.
>
> The radiological aspect of pulmonary tuberculosis among workers examined is on the other hand highly important, since it shows an atypical picture on which are noted lesions with unusual sites and apical and subclavicular regions unaffected. It is this fact which has led me to admit the probability of a combination of pneumoconiosis and tuberculosis.
>
> Finally, statistical as well as radiological data justify absolute exclusion of the theory of a particular benign or malignant course of tuberculosis among marble workers, as likewise of any kind of predisposition to the said specific disease.

South Africa

Mining started in South Africa on the Witwatersrand in 1886 (80). At first the workings were shallow and in the oxidized or "free-milling" zone where the rock was relatively soft, friable, and damp. By 1892 extensive deep-level properties had been operated, and drilling by machines was introduced. As long as the mines were working in the free-milling zone very little dust was produced, as the mines were shallow and probably fairly well-ventilated, and it is unlikely that the men were greatly affected by the dust. Very few people in South Africa suspected that mine dust was in any way injurious to health until the Government mining engineer of the Transvaal Mines Department in a report in 1902 mentioned "miners' phthisis" as a disease "which seems to be peculiar to men employed in rock-drill work." This report, which covered the 6 months ended December 1901, stated that of 1,377 machinemen employed previous to 1899, 225 were known to have died between

October 1899 and January 1902, an average annual death rate of 73 per 1,000. These facts arrested the attention of the Government, the mining community, and the general public, and in December 1902 the first (Transvaal) Miners Phthisis Commission was appointed "to inquire into and report on the disease commonly known as miners' phthisis." A report was issued in 1903. The commissioners attempted to procure a medical examination of all working miners, but the returns were incomplete partly because many of the miners were reluctant to submit themselves to examination. Of the 1,201 miners examined 15.4 percent were affected by miners' phthisis and 7.3 percent were suspected. The Report of the Medical Commission issued in February 1912 was the second landmark in the medical history of silicosis in South Africa. The actual examinations were more complete than in 1903 but did not cover all the underground employees. A general clinical examination was made of 3,136 working miners, supplemented by a special examination of 326 men, in which radiography was for the first time applied to the examination of cases on a fairly extensive scale. The prevalence of the disease among the working miners examined was found to be 26 percent, with an additional 5.5 percent of doubtful cases. This figure is somewhat higher than that found in 1903 but probably reflects the result of a more extensive investigation.

According to Irvine, Mavrogordato, and Pirow (81) 1916 was a cardinal year in the history of silicosis on the Rand. It was marked by the institution of the Miners' Phthisis Medical Bureau and the publication of the General Report of the Miners' Phthisis Prevention Committee. The present-day system of detection and prevention of silicosis on the Rand dates from 1916. A total of 6,472 original compensation awards were made to miners for silicosis from 1912 to 1916.

According to the Report of the Miners' Phthisis Medical Bureau (82) for the Three Years Ended July 31, 1932, the average number of new cases of silicosis and tuberculosis with silicosis among the miners of the Witwatersrand was over 800 annually during the 4-year period 1912-16. The report also states that 895 cases of "primary-stage" silicosis were detected from 1917 to 1920; 728 cases of "anteprimary stage" from 1920 to 1923; 1,235 cases of "anteprimary stage" from 1923 to 1926; and 917 cases of "anteprimary stage" from 1926 to 1929. In 1930-31 the number of new cases for the first time in 8 years fell below the standard level of 251 cases, which was the average annual production for the period 1920-23.

The following statement by Hildick-Smith (83) summarizes briefly the status of miners' phthisis in South Africa. After quoting figures showing the percentage production rate of silicosis for the preceding 15 years he said:

> From a study of these figures I personally am inclined to think that the time is not far distant when the incidence of silicosis will have ceased to be a matter of serious concern to the industry. This, I think, will be accomplished by the elimination, in whole or in part, of the dangerous dust from the underground air. Old habits of thought were inclined to persist in regard to the production of silicosis on the mines. The report on the work of the Miners' Phthisis Medical Bureau showed the

maximum percentage production rate for silicosis had decreased from 14.5 percent after 14 years' service in the period 1918-20 to 4.5 percent after 17 years' service in 1931-32. The graduation rates for all miners, including men working underground before the inception of the Phthisis Bureau in 1916, show that the present maximum production rate is under 4 percent after 20 years' service. Of the 157 miners notified last year that they had contracted silicosis more than one half began work in 1916-17, one in 1922-23, and one in the following year. Since 1923 there have been no cases of contracted silicosis - in other words no new Rand miner has been found suffering from silicosis in the last 10 years. These results are confirmed by the fact that less than 50 percent of the patients at the Springkell Sanatorium are of the miner class.

With regard to the employment of silicotics, Hildick-Smith said that 978 are now employed by the mines - an increase of about 110 since November 15, 1933.

United States

Data are not available on the general incidence of silicosis in the United States. Such data are difficult to obtain in the existing state of American vital statistics; exact knowledge of the population at risk in a given occupation, classified by age, is obtainable only with great difficulty and by special and intensive research (37). In an analysis of statistical data of this kind Greenburg (37) calls attention to the importance of considering groups that are fairly comparable, so that the effect of industrial hazards will not be complicated by the influence of social and economic factors of a more general nature. He states, for example, that in Hoffman's studies published in 1918 ratios presented for the various dusty trades are based on the industrial experience of the Prudential Insurance Co. but that the ratio used as a norm for comparison of males in the registration area was obtained from data of the United States Census Bureau. On this basis almost all the industries which he tabulates show a surprisingly high tuberculosis ratio, including many trade designations of workers, such as "iron and steel workers", who can hardly be considered as generally exposed to a serious dust hazard; his abnormally high ratios, therefore, probably are due to the general social and economic conditions of the wageearner's life and to the fact that the group is an industrial one. It seemed evident to Greenburg (37) that a comparison between the Prudential figures for a given dusty trade and the Census figures for all occupied males, which gave Prudential ratios 25 to 50 percent higher for tuberculosis than those for the registration area, was not a fair one and that the conclusion reached through such a comparison was unwarranted.

Several special investigations, carried out in certain industries in the United States, that have attracted attention because of the high death rate from tuberculosis (84) are described below.

Mining.- The first investigation of silicosis in the mining industry in the United States was made in 1914-15 by the United States Bureau of Mines in cooperation with the United States Public Health Service in the Joplin

(Mo.) mining district (85). Of 93 men examined 64 showed plain and definite evidence of pulmonary disease, 3 were suffering from nonpulmonary disease, and 26 were seemingly well. To gain a more accurate idea of the prevalence of consumption among the miners in the Joplin district it was decided to examine a large number, and from May 15 to December 31, 1915, 720 miners were examined; 45.7 percent had silicosis and tuberculosis and 5.3 percent had tuberculosis. A later report (1927) of this same investigation by Lanza and Childs (86) contained the first detailed X-ray studies of silicosis made in the United States.

Investigations of mining conditions by Harrington and Lanza (87) in Butte, Mont., in 1921, revealed that 42.4 percent of 1,018 miners examined showed definite signs of lung damage due to dust. An examination in 1921 of 303 gold miners in Nevada disclosed that 80 percent had silicosis, and a study in California in the same year revealed that 25 percent of 181 gold miners had silicosis.

In 1923 the mining companies of the Tri-State district (comprising the zinc- and lead-mining areas of southwestern Missouri, southeastern Kansas, and northeastern Oklahoma) asked the United States Bureau of Mines to determine whether measures in use were adequate for the prevention of silicosis and, if not, to recommend improvements. The 1923 investigation (88) included the examination of 309 miners, 101 of whom were found to be negative, 114 doubtful, and 94 positive cases of silicosis. Of the positive group 52 were in the first stage, 22 in the second stage, and 20 in the third stage of silicosis.

From July 1, 1927 to June 30, 1932 the Metropolitan Life Insurance Co., the Tri-State Zinc & Lead Ore Producers Association, and the United States Bureau of Mines operated a cooperative clinic at Picher, Okla. (89), to demonstrate to industry a workable method for diagnosis of silicosis, to educate workers in preventive measures, and to serve as a model to industries presenting a dust hazard. During this period, of 27,553 individuals examined, 5,366 had silicosis, 742 silicosis plus tuberculosis, and 320 uncomplicated tuberculosis.

According to the United States Public Health Service (90) the percentage of anthracite miners and their helpers showing signs of pneumoconiosis increased from 2 percent among those with less than 5 years' service to 16 percent among those with more than 15 years' service (for persons under 45 years of age). Of 95 X-rays of bituminous-coal miners 40 (42 percent) showed generalized fibrosis, chiefly linear in character. The percentage of deaths caused by all respiratory diseases among anthracite miners in Pennsylvania was definitely higher than that of other adult males in the general population - 57.6 percent in contrast with 37.2 percent among other men of the same age in the Wilkes-Barre coal field (91).

Kibbey (92) reported in 1931 that practically 100 percent of the miners who worked in the several coal mines operated by his company in Alabama had anthracosis and that they had a higher mortality rate from tuberculosis than any other wageearning group.

From a study of industrial morbidity statistics for the period 1924-27 Bloomfield (93) found that 38 cases of pneumonia had occurred among the 1,637 bituminous-coal miners employed during the same period in the mines operated in connection with an iron and steel plant. Occupational analysis disclosed that 33 of the 38 pneumonia cases were associated with only 2 of the 69 different occupations in the mines - pick-mining and loading coal. The pneumonia rate per 1,000 for miners and loaders was 31, whereas the rate for all other mine workers was only 8.5 per 1,000.

The apparent similarity of the risk in mining and the risk in the processes involved in excavating and tunneling, so far as the silicosis hazard is concerned, led to an investigation of such processes in New York City by Smith and Fehnel in 1929 (84). Of the 208 drillers, blasters, and excavators examined 42 percent showed early and 15 percent well-developed silicosis. Evidence of tuberculosis, including both active and inactive cases, was found in 9 percent of the total number.

Grinding.- According to Hoffman (4) the industrial insurance mortality statistics of the Prudential Insurance Co. from 1897-1914 showed that 143 (46.9 percent) of 305 deaths among grinders were due to pulmonary tuberculosis. In another group of 5,988 grinders, which included cutlers, scissors grinders, ax, plow, and other steel grinders but excluded foremen and superintendents, the actual mortality from all causes was 17 percent in excess of the expected mortality; in other words, for every 100 deaths expected on the basis of normal experience there were 117 deaths among this group.

In 1920 Winslow and Greenberg (94) investigated the dust hazard in an ax factory. They quoted Drury's exhaustive statistical study on the incidence of tuberculosis among grinders and polishers as showing that from 1900-18 the death rate in a group including 90 polishers, 85 wet grinders, and about 25 dry grinders was 1,000 percent. Their investigation revealed dust conditions serious enough to cause such an excessive death rate.

To indicate the effect of silica as a predisposing cause of tuberculosis Riddell (95) in a paper published in 1926 quoted the following mortality table prepared by Drury for a Connecticut community (agricultural except for an ax factory employing 800 men):

Death rate from tuberculosis in a Connecticut community

Entire population of factory district	200 per 100,000
State as a whole	150 per 100,000
Factory population	650 per 100,000
Polishers and grinders	1,900 per 100,000

In a review of the pulmonary tuberculosis developed in a large grinding-wheel plant Clark (96) found that from January 1, 1918 to December 31, 1930 there had been 42 cases of active pulmonary tuberculosis, 38 of whom were men and 4 women; 37 of the group were employed at factory work of some kind, while 5 did clerical work. Of the 42 workers who had developed tuberculosis

20 were dead at the time Clark prepared his report, 18 were living, and 4 could not be traced. Of the 18 living 13 were working, 3 were at home under care of a physician, and 2 were in hospitals. The average number of employees during the 13-year period was 2,460.

According to Kessler (97) over 100 cases of silicosis were alleged to have occurred in the abrasive-powder industry in one State involving 4 companies which pumped sand by hydraulic pressure to a plant, where it was washed, steam-dried, screened into various sizes, and then pulverized in closed tube mills. Six of the workers had died and been autopsied and many others were reported to have died, but the results of the autopsies were not known.

Granite industry.- In his report of dust phthisis in the granite-stone industry, published in 1922, Hoffman (98) summarized the results of his investigation as follows:

> The granite-stone industry is carried on by wageearners who, broadly speaking, live under sanitary conditions above the average, so that possibly unfavorable environmental factors are of decidedly secondary importance.
>
> The housing conditions under which granite workers live are also above the average, so that in this respect the environmental factors are favorable to a low mortality rather than otherwise.
>
> Anthropometric records clearly establish the fact of a superior physique, indicative of a higher degree of disease resistance, as determined by a relative weight above the average. From this point of view, therefore, granite workers should experience a relatively low mortality from pulmonary tuberculosis instead of a mortality decidedly above the average normal to industrial occupations.
>
> Granite workers, considered by specific occupations show wide variations in tuberculosis frequency, the excess in the death rate being most marked among the men employed in granite-stone cutting, it being especially severe among men employed in the use of pneumatic tools. Certain occupations, such as polishing, tool sharpening, bed setting, etc., do not show a marked excess, if any, in the mortality from pulmonary tuberculosis, clearly indicating that the risk is practically proportionate to dust exposure.
>
> Compared with the normal death rate of adult males of the State of Vermont, or of New England, the mortality from pulmonary tuberculosis among granite-stone workers has increased enormously during the last 2 years, as contrasted with a diminishing mortality in the population at large. Against a decrease in the pulmonary tuberculosis death rate of adult males of the State of Massachusetts from 288.5 per 100,000 exposed to risk during 1895-99 to 203.2 during 1915-18 there had been an increase in the corresponding death rate of granite cutters of the

New England States from 432.0 per 100,000 during 1895-99 to 1056.7 during 1915-18. The only other occupation for which information is available for the corresponding period of time is that of glass-bottle blowers, among whom the mortality from pulmonary tuberculosis diminished from 418.6 per 100,000 to 265.9. These statistics for the New England States are confirmed by similar data for every other stonecutting center of the United States, proving with absolute certainty that in every section of the country the tuberculosis mortality of this group of industrial workers is increasing, in contrast to a locally diminishing death rate from this most fatal of all diseases * * *.

Recalling that the normal pulmonary tuberculosis mortality of adult males in Massachusetts is only 203.2 per 100,000, it is shown that the present death rate from pulmonary tuberculosis among granite cutters is 5 times the normal experience in the population at large and probably 6 times what it should be on the basis of strictly noninjurious occupations carried on largely under hygienic conditions and in the open air.

The same conclusion applies to nontuberculosis respiratory diseases, for it is shown that the mortality from bronchitis, pneumonia, and asthma is also on the increase among granite cutters, in contrast to a diminishing rate of frequency among adult males of the general population.

In the second series of investigations on health of workers in the dusty trades the United States Public Health Service studied the granite industry at Barre, Vt. (99). The occupational groups were divided into four general classes based on the amount of dust to which they were exposed. These groups consisted of:

(A) Hand pneumatic-tool cutters, 614 persons, exposed to an average of approximately 60 million particles.

(B) All other occupational groups exposed to more than average plant dustiness. This group contained 104 persons in occupations where the dustiness averaged between 27 and 44 million particles.

(C) Those occupational groups consisting of 146 persons exposed to average plant dustiness (20 million particles).

(D) Those occupational groups exposed to less than average plant dustiness. This group contained 108 persons in occupations where the dustiness averaged between 3 and 9 million particles.

The following summarizes in part the results of the study on prevalence of silicosis and tuberculosis among these workers:

Having a clear-cut diagnosis of silicosis and complete information with regard to the magnitude of dust exposure, it was possible to study the proportion of persons developing silicosis by length of service. In the A group, or that group in which there was heaviest dust exposure,

the first case of silicosis appeared after approximately 2 years of service, and by 4 years of service all in this group seemed to have developed at least an early case of silicosis. In the same dust-count group the first case of more developed silicosis appeared after 5 years of service, and by 9 years approximately 90 percent had advanced to this stage. The study of the other dust-count groups showed that the development of silicosis was proportionate to the dust exposure. In the case of the D group, 2 cases of early silicosis occurred after 10 years' exposure, and 1 case of moderately developed silicosis after 6 years' exposure.

General prevalence of tuberculosis complicating silicosis.- In plants carrying morbidity records, where it was believed certain that all cases of tuberculosis were diagnosed as such, the total rate was 5.7 percent or 6.5 percent if early cases are included. Latent or suspected cases of tuberculosis (among those given physical examinations) gave an additional 3.8 percent. These figures represent the number of cases found over a period of 2¼ years, and consequently the rate is different from what would be obtained on an ordinary cross-section survey.

Tuberculosis by dust groups and years in granite.- The association between the high tuberculosis prevalence among granite workers and the dust hazard was shown by determining the rates for that disease in the different dust-count groups by length of service in the granite industry. The comparison between A and B groups and C and D groups was extremely significant. No cases were found in the D group, and C group furnished but 3 cases, 1 of which occurred under 5 years' exposure; another, under 10 years. Of particular importance is the fact that in 35 years of exposure the rate did not rise. Rates for the A and B groups rise steadily with increase of length of service to 15.5 percent in group A and 19.1 percent in group B. Even when the suspected tuberculosis cases are added, the general picture is not materially changed. In neither the C or D groups does there occur any excess of cases after long exposure, while in the A and B groups the rate rises with length of service in a similar manner as for active tuberculosis.

According to Goodrich (100) statistics show that workers exposed to silica dust and, to a smaller extent, other dusts have an excessive death rate from tuberculosis. The introduction of pneumatic and electric tools in processing stone has caused a tremendous increase of tuberculosis of the lungs in those working with these appliances. In 1890 when stone was cut and polished with comparatively crude tools the death rate from tuberculosis among these workers was 150 per 100,000. By 1910 it had increased to 1,080 per 100,000 and by 1925 had reached 1,950 - an increase to 13 times that of the period before high-speed tools came into use. The explanation, of course, is that modern equipment creates many times the density of dust in air produced by manual labor. Cases of silicosis also became very numerous, and many of them developed tuberculosis. During this same period, when tuberculosis was increasing so rapidly among these workers, the death rate from tuberculosis throughout the country was reduced to about half the rate of 1890.

The report of the Special Industrial Disease Commission of Massachusetts (101) shows that the granite industry presents a severe silicosis hazard. Surveys were made of 314 granite establishments, and dust studies were made in 13; X-rays and physical examinations were made of 961 graniteworkers; 15.2 percent were found to have silicosis and 7.6 percent silicosis with tuberculosis.

Foundry industry.- The Special Industrial Disease Commission of Massachusetts surveyed 225 foundries (101), in which 12 dust studies and 1,614 physical examinations and X-rays were made. In the foundries studied excessive dust counts were found in connection with many of the operations. The need for immediate, effective control of dust conditions in foundries was evidenced by the fact that silicosis was found in 8.8 percent and silicosis with tubersulosis in 2.6 percent of the workers examined.

In a study of the foundry industry McConnell and Fehnel (102) found that the death rate for respiratory diseases (including all forms of tuberculosis and influenza) for iron and steel foundry workers was about two and one third times that for workers in all industries combined and was more than twice that for workers in any of the industries selected for comparison. More than a third of all deaths among foundry workers were caused by some respiratory disease, whereas but little more than a fifth of the deaths of workers in industry were due to these causes. A striking fact revealed is the uniformly high death rates for foundry workers for each of the respiratory diseases throughout the working period of life. Another outstanding fact is the high rate for pneumonia, bronchitis, etc., the foundrymen's rate being nearly three times that for all workers combined. Among iron and steel molders, founders, and casters, where 12 deaths from pneumonia might have been expected, there actually were 38, a ratio of actual to expected deaths of 315 percent; 24 deaths were recorded for respiratory tuberculosis, where 13 might have been expected, a ratio of 179 percent; the ratio for influenza was 216 percent, based on 23 actual compared with 11 expected deaths. In an analysis of the occupational mortality of adult white male industrial policyholders of the Metropolitan Life Insurance Co. who died during 1922-24 a comparison is made of the proportion of deaths due to any one cause in any one specified occupation group with the proportion due to the same cause among all occupied white males. Again, pneumonia was the leading cause of death among foundry workers, a condition not true of any of the other 71 occupations included in the analysis. When differences in the age composition of the two groups were taken into account it was determined that the proportion of deaths from pneumonia was 120 percent higher for foundrymen than for occupied males generally. Likewise, the proportion of deaths from influenza was 82 percent higher, that for tuberculosis of the respiratory system 5 percent higher, and that for other respiratory diseases 17 percent higher. McConnell and Fehnel (102) emphasize the harmful effects on the lungs of exposure of workers to dust inhalation; 67 of 215 X-rays taken were diagnosed as positive for silicosis. Advanced cases of silicosis were not found among those examined, but sufficient evidence of occurrence of the disease was presented.

Cement industry.- A 3-year study of the cement industry by the United States Public Health Service (103) revealed the following:

X-ray films were obtained of the chests of 53 employees in several different occupational groups, length of service varying from 6 months to 15 years. On the basis of the findings, these employees were classified into 5 groups, as follows: (1) Those showing evidence of pneumonoconiosis, (2) those showing evidence of tuberculosis and pneumonoconiosis, (3) those negative for pneumonoconiosis, (4) those showing evidence of tuberculosis without pneumonoconiosis, and (5) doubtful cases.

The earliest case of pneumonoconiosis appeared after 3 years' exposure to cement. Of the 53 men selected, 37 had been in the industry more than 3 years and are therefore used as a basis of comparison. Among these 37 men, 15 showed evidence of pneumonoconiosis, 3 of the 15 also having tuberculosis. In the group of 22 who showed no evidence of pneumonoconiosis 8 gave evidence of arrested tuberculosis, 4 showed no evidence of either pneumonoconiosis or tuberculosis, while 10 were considered doubtful.

In none of the cases showing pneumonoconiosis were there any clinical symptoms of the condition, although the general fibrosis present and its distribution through the lungs were indicative of the condition. Cement workers appeared to have more than a normal amount of calcified nodes in the lungs.

Of the 570 workers examined, 21, or 3.7 percent, were diagnosed as either positive or suspected cases of pulmonary tuberculosis. In only 2 cases, however, was the disease active at the time of the first series of special chest examinations, and neither appeared to progress as the result of exposure to the dusts. In the history of both cases it was evident that the disease had developed before the men entered the cement industry. One of them died about a year after the study closed, while with the other the disease appeared to have become quiescent when the study was closed. All the rest of the cases, with the exception of three, which were doubtful as to diagnosis, appeared to have developed their lesions before they entered the industry and were continuing in their occupations without any evidence that the lesions were progressing.

According to Russel (104) the frequency of disability on account of respiratory diseases among the cement workers was twice as great as the average respiratory rate among employees of 11 manufacturing plants in relatively nondusty industries. The highest rate for all respiratory diseases in any one of these establishments was 30 percent below the rate for cement workers.

Canada

Elliott (105) was the first to direct attention to silicosis in Ontario, Canada; in an article on Silicosis in Ontario Gold Mines published in 1924 he reported that 3 of 11 underground workers examined by him presented evidence of silicosis, indicating that the disease was being produced in this mining area. In 1925 and 1926 a further survey was made by the Industrial Hygiene Division of the Ontario Department of Health. Miners with more than 5 years' experience underground in the individual mining area and with no exposure to silica dust elsewhere (a few of those examined had had some exposure elsewhere) were given a physical examination. Of 1,220 men examined 74 showed evidence of silicosis - 52 in the anteprimary, 11 in the primary, and 11 in the secondary stage.

During the period April 1, 1926 to April 1, 1927 a survey of silicosis was made in the Porcupine group of mines in Northern Ontario under the auspices of the mine operators in compliance with the amendment to the Miners' Phthisis Act of April 8, 1926, bringing silicosis under the status of a compensable industrial disease. Approximately 4,000 miners were examined for tuberculosis, silicosis, or both. As a result, 94 silicosis claims were submitted for compensation. Using the South African nomenclature, of these 94 cases 39 were diagnosed as anteprimaries, 28 as primaries, and 27 as secondaries; in addition, 247 men showed either positive or probable tuberculosis (106).

Types of Dust Injurious to Health

The relation between dust inhalation and lung diseases was recognized very early, as indicated by the literature cited above, but it was also recognized that certain dusts caused severer symptoms with quicker fatal issue than others. As the symptoms caused by inhalation of certain dusts were long delayed or were attributed to other causes, such dusts were considered harmless and some even beneficial in the prevention of lung diseases when inhaled with the more harmful ones. Ancient writers seldom distinguished between the various forms of respiratory diseases but rather referred to a general relation between lung affections and dust inhalation (28), and no really scientific investigations were made of the workers or the dust. Ramazzini, however, described the effects on workers of various types of dust produced in such industries as the hemp and flax industry, silk-combing, and corn-sifting, in addition to mining and similar industries. According to Collis (28) the distinctions, implied or definitely stated, in Ramazzini's excellent clinical description of the types of respiratory trouble which follow inhalation of different dusts

> are the more notable, because even today pneumonoconioses are pigeonholed in clinical teaching as a single entity, ascribed to exposure to any and every form of injurious dust, of which pulmonary fibrosis sums up the pathological findings and phthisis the morbid result.

In the decade preceding 1862, when the study of public health was organized in England (28), Greenhow made an elaborate statistical inquiry into the influence of occupation on health in connection with lectures on public health at St. Thomas' Hospital. Simon, then medical officer to the General Board of Health, considered Greenhow's investigation so important that his report was published by the board, and shortly after when Simon became medical officer to the Privy Council he intrusted Greenhow with the duty of further investigations in the great industrial centers. The resulting reports are, according to Collis (28), the first example of State medical inspection of factories, and he makes the following statement regarding them:

> Throughout these reports runs as a theme the influence of dust inhalation in causing pulmonary disease, whether among lead miners in Yorkshire, tin miners in Cornwall, needle pointers in Alcester, cotton operatives in Lancashire, flax hecklers in Pately Bridge, metal grinders in Birmingham and in Sheffield, coal miners in South Staffordshire and in South Wales, or stone dressers in Stroud. Why work so well started was then allowed to lie dormant for so long, while other aspects of public health were being strenuously developed by medical officers of health with inspectors of nuisances appointed for every town and district, reinforced now by a battalion of tuberculosis officers, is astonishing.

As a result of investigations in South African mines and in other mining districts of the world, so much attention was focused on one particular dust - silica - as the most harmful encountered in industry that most investigators had accepted other dusts as harmless or of negligible importance as a health hazard in industry and the disease - silicosis - resulting from breathing silica dust as the only important dust disease. Other dusts, such as the silicates (asbestos, for example), have been found almost as harmful as silica dust, but the effect on the lungs is somewhat different from that of silica and the hazard not so widespread.

From general underground experience for more than 25 years in coal and metal mines and from an intensive study of dust for 8 years Harrington (107) concluded that -

> Any dust insoluble in the fluids of the respiratory passages and in sufficiently finely divided form to float in the air and be breathed by underground workers will ultimately be harmful to health if the dust is in the air in large quantities and is breathed by workers for considerable periods of time. This applies to insoluble nonmineral as well as mineral dusts or mixtures of them and includes coal dust or mixtures of coal and other dusts. There are also some definitely harmful mine dusts which are soluble, and some dust experts appear to believe that the so-called insoluble dusts under certain conditions become soluble and are harmful only when soluble.

An outstanding impression gained by Ballantyne (108) from the reports of the International Conference on Silicosis was that silicosis constitutes only

one facet of a very large question - the prejudicial effect of dusts in general upon the human subject. He concluded that -

> It (silicosis) is only one of several close-related pulmonary affections, due to dusts of different kinds. It is the most important of these, but only because it is the most definitely known and so many workpeople are exposed to the risk. In the case of asbestos dust knowledge regarding the injurious effects of inhaling it has advanced so far as to justify the adoption of legislative measures analogous to those relating to silicosis. There are many other kinds of dust, however, as to the effects of which, when inhaled, we have little or no knowledge, and the investigation of which calls for early attention.

The Report of the Silicosis (Medical Arrangements) Committee issued in London in 1929 (109) contains the following statement:

> We are convinced that silicosis is more widespread than is generally believed and that it occurs to some extent in a number of industries and occupations where its presence has not been suspected.

In 1930 Kettle (110) called attention to the harmfulness of breathing dust:

> Dusts of various kinds occur in the atmosphere in all parts of the world, and the inhalation of these dusts over periods of years inevitably produces changes in the lungs. Everyone is familiar with the pigmented lung of the city dweller, an example of a pathological change produced by the inhalation of dust which is of no clinical importance whatever, but an exaggeration of this condition in the coal miner causes definite symptoms, and when the inhaled dust is not the relatively harmless carbon, but one of the much more sinister possibilities, serious pulmonary changes develop. The pneumonoconioses have received less attention than they deserve, even in textbooks of medicine and pathology. But to the doctors whose patients are exposed to dusty trades, to those responsible for the conduct of these trades, and to the factory inspector, pneumonoconiosis is of great moment.

In the report of a study of dust conditions in German industries, published in 1932, Lochtkemper and Teleky (66) stated in the summary:

> The breathing of any dust leads to injury of the lungs, if it is intensive enough and continued long enough.
>
> With intensive and long-continued inhalation of dust, entirely quartz-free dust leads to lung changes clearly recognizable in the X-ray picture. The blood vessels appear more clearly defined; there are also more numerous and thicker honeycomb formations, also infiltrated mottling which, however, never shows the very sharp delineation and density caused by quartz. The subjective symptoms referable to the changes are slight; there is none of the lung rigidity characteristic of silicosis but a complication of diseases, especially bronchiectasis and emphysema.

It is theoretically possible from the report that many of the occupational dusts breathed in immense amounts over a very long time lead to changes not recognized by us today.

In a discussion of the etiology, pathology, and physical signs of silicosis Levey (111) stated:

> However, a lung filled with dust is a wounded lung and should be considered as subnormal in its vital resistance toward the onset of disease. A lung containing silica dust has a strong predilection toward the onset of tuberculosis. This susceptibility is unusual.

Terminology of Dust Diseases

The following terminology of dust diseases of the lungs (112) is now used by most writers on the subject:

Pneumoconiosis.- A general term covering all dust diseases of the lungs, fibrous or nonfibrous (from Greek pneumon, lung, and konis, dust).

Silicosis.- A fibrosis caused by free silica (or quartz) and the best known scientifically of the dust diseases of the lungs.

Silicatosis.- A type of fibrosis found after exposure to certain mineral dusts and assumed to be caused by various silicates. It is distinct from the sharply defined, coarse, nodular fibrosis caused by silica dust.

Anthracosis.- A dust disease of the lungs found in coal miners; it is ill-defined and is presumed to depend on inorganic dust in coal. The lungs are black.

Siderosis.- A term applied to a fibrosis of the lungs found in metal workers. The condition is ill-defined. The lungs are yellow or red from metallic oxides, generally of iron.

Asbestosis.- A fibrosis of the lungs with characteristic microscopical stigmata due to breathing asbestos dust, a silicate of magnesium.

Pneumoconiosis

The diseases resulting from the inhalation of dusts generated in industry during the progress of certain processes are generically known as pneumoconiosis, having been so named by Zenker, as mentioned previously. In a brief summary of information regarding certain of the pneumoconioses other than silicosis Collis (113) called attention in 1931 to some of the respiratory diseases that may be caused by dust but seldom are recognized as dust diseases. The inorganic dusts he classed as insoluble, soluble and harmful, and mixed. Under insoluble dusts he mentions that those from certain materials, such as basic slag and emery, an oxide of aluminum, are insoluble in the tissues. Inhaled particles fall on the walls of the bronchi and bronchioles, where they are entangled in secreted mucus and then swept back by ciliary

action to be expelled finally in sputum. If the dust exposure is excessive over a period of time an inflammatory hyperemia of the walls results, with an excessive exudation of mucus; finally the process extends beyond physiological elasticity; then degeneration and destruction of the ciliated mucosa occur; microbic invasion follows; and chronic bronchitis is established.

The process described by Collis is a reaction to the inhalation of all dusts not rapidly absorbed; hence bronchitis stands out as chief of the dust diseases and during middle life causes much recurrent invalidity and incapacity and, after middle life, high death rates. Dust bronchitis cannot be distinguished clinically from bronchitis due to exposure at hot furnaces, fumes in industry, or severe climatic conditions; hence it association with dust inhalation lacks recognition.

If the dust particles are small enough (5 microns or less) to be drawn into the finer bronchioles and alveoli, which are the seat of attack for pneumococci, a similar reaction is stimulated; hence the resistance of these parts to infection is lowered, and pneumonia results. Pneumonia is even less-recognized as a dust disease than bronchitis; nevertheless, mortality records of those employed in dusty occupations are high. However, when fine particles of insoluble dusts are carried by phagocyted dust cells from the alveoli into the lymph stream and lymph nodes of the lungs they tend to remain there as foreign bodies and do not provoke any particular tissue reaction.

Collis (113) says that the most-studied dust of the soluble and harmful dusts in this group is that of silica. Next come the dusts of silicates; although many silicates, such as fire clay and pottery clays, appear to exert little if any harmful influence upon the lungs recent work has shown that certain other silicates, such as basalt and asbestos, react injuriously on the pulmonary tissues. The reason for these differences is not clear; but probably it lies in the constitution of the various silicates, the SiO_2 radical being less firmly attached to the molecule in some cases than in others.

Collis (113) defines asbestosis as a pneumoconiosis that advances to a fatal end without the supervention of any characteristic infection. It is a simple dust condition, just as is simple silicosis; but it is more distressing in life and more rapid in this progress than silicosis. It contrasts even more strongly with pulmonary mycosis, which is due to a living infection upon otherwise healthy lungs.

Regarding the mixed dusts, Collis (113) says that as long as any dust consists of only one substance its influence can be isolated and studied; but the case is different when more than one substance is present in the dust. Coal dust, which recently has been carefully investigated (114), is taken as an instance in point. No undue mortality from respiratory diseases is said to be found among coal miners as long as the coal worked contains little or no mineral matter - presuming that the miners are not exposed to other dusts, such as those arising from rocks intervening in the coal measures. The miners in the Nottinghamshire coal fields furnish a good example; the lungs of these men may be as black as the coal they work, but they remain resilient and free from fibrosis.

In discussing the nomenclature of dust diseases Pancoast and Pendergrass (22) state that although silica (SiO_2) seems to be the active fibrosing agent in most conditions recognized as essentially a pulmonary fibrosis adherence to the general term "pneumoconiosis" still seems advisable. Some other dusts undoubtedly cause a fibrosis directly, and still others may either tend to retard the action of silica, as coal dust and clay, or enhance its action, as alkalies in the mixtures of silica and powdered soap in scouring powders. Silicosis is the word much more frequently used, mainly because it is not so unwieldy and usually describes accurately the particular phase of the condition under discussion. "Miners' phthisis" appears in the laws of South Africa but is otherwise an obsolete term generally recognized as implying silicosis or pneumoconiosis. There is now reason to believe that silicates also produce considerable fibrosis through their silica content or because certain silicates have a specific action of their own.

According to Pancoast and Pendergrass (22) there is even more reason to employ the occupational terms now than in the past because recently certain peculiarities have been attributed to the dusts of those industries, even though the condition still remains silicosis or pneumoconiosis. For example, in anthracosis the action of the silica seems to be modified by the coal dust mixed with it; moreover, coal dust alone may produce a mild fibrosis. Collis and Gilchrist (114), in a recent investigation of coal trimmers working at the Cardiff docks, found that inhalation of large amounts of coal dust alone over a period of years produced evidences of mild pneumoconiosis which presented the same roentgenographic appearances as silica. It has been suggested that clay has a similar effect in protecting the workers in some of the operations in pottery industry, but not all of them. The term "chalicosis" has been applied in the past to pneumoconiosis of potters.

In recent years certain very unusual features in connection with pneumoconiosis among asbestos workers have brought the term "pulmonary asbestosis" into active use.

According to Haldane (115) evidence is accumulating constantly that scattered fibrosis, giving essentially the same X-ray picture as early silicosis, is comparatively common as a result of excessive dust inhalation, but without accompanying liability to tuberculous infection. However, he thinks that this condition should not be called silicosis, and since it seems to arise from excess of any kind of dust and not merely silicate dust pneumoconiosis seems the most suitable name for it.

Silicosis and asbestosis are forms of pneumoconiosis that have been clearly defined clinically; the other forms of pneumoconiosis, as anthracosis, siderosis, and many others, still lack complete definition. Although considerable radiographic evidence has been accumulated on these latter types of occupational dust exposures corroboratory evidence has not been deduced from correlations of the X-ray findings with pathological anatomy, chemical examination of tissues, and studies of the industrial environment (116).

Silicosis

Definition

Rovida (117), the first to mention silicosis, used the term in 1871 in describing "a case of silicosis of the lungs with chemical analysis."

At one time it was believed that several substances were capable of producing the lung condition called silicosis, but it is now agreed fairly generally that all types of dust fibrosis of the lungs are due to some form of the element silicon (118). The recognition that silicon was the important element in pneumoconiosis was a great step forward but, according to a recent statement by Kettle (118), there is no doubt that the teaching that only one form of silicon - the oxide silica - is capable of producing the disease was accepted too readily. The realization in recent years that asbestos can produce serious pulmonary fibrosis should have been a warning that a too-restricted view was being taken of the matter; this has been borne out by the recent work of Jones on sericite. However, the following definition adopted at the International Silicosis Conference in South Africa in 1930 (119) is still accepted:

> Silicosis is a pathological condition of the lungs due to inhalation of silicon dioxide. It can be produced experimentally in animals.

Symptoms

Inhalation of silica dust usually is not accompanied by evidences of irritation and if free from other irritating dusts may be breathed without arousing suspicion of its dangerous character (99).

The following discussion of symptoms of silicosis is based on the findings of 9,662 examinations of 7,722 employees at the Picher Clinic of the Bureau of Mines in 1928 (88).

<u>Shortness of breath</u> has been generally recognized as the cardinal symptom of silicosis. Dyspnea accompanies exertion in the earlier stages of silicosis and increases progressively until in the later stages it often prevents any labor. The apparent distress on exertion frequently noted in silicotics who deny shortness of breath seems out of proportion to the very slight rise in pulse rate taken 2 minutes after exertion.

<u>Chest pains</u> were admitted frequently, generally anteriorly, and more often on one side only. In many instances the pains seemed of a reflex character. In nearly all cases they were vague and flitting and did not seem to interfere with manual labor. Pains in the shoulder and possibly in the posterior part of the chest probably are considered by many of the men as "rheumatic"; such pains seem partly responsible for the large number of complaints of rheumatism.

<u>Cough</u> is a symptom frequently admitted in silicosis and generally is unproductive.

Expectoration as a symptom was admitted infrequently. When present in uncomplicated silicosis the sputum usually is clear or has a bluish tinge and is of a viscid, tenacious consistence, very difficult to cough up. The color of expectoration may be due to the color of rock mined.

Hemoptysis appeared to be more common among silicotics than was expected. In some instances, particularly in second- as well as in third-stage silicosis, fibrotic areas may mask a tuberculous lesion which remains unrecognized until it becomes an open lesion, when the sputum will show the tubercle bacilli or hemorrhage will call attention to the true condition.

It seems probable that some of the admitted night sweats were not true pathological night sweats, but the relatively high incidence in the silicotic groups appears difficult to explain except on the assumption that at the time of the sweats some active infectious process was in progress. This could be due to tuberculosis; it may have been due to a pyogenic infection or malaria, as 33 percent of the silicotics examined gave a history of previous attacks of malaria.

The loss of strength admitted by silicotic in most instances probably was connected with their dyspnea on exertion and was due to respiratory insufficiency. This probability is strengthened by the small number of silicotics with poor physical development (4 of a total of 1,062).

Gastrointestinal symptoms were pronounced in the more advanced cases, and loss of appetite was admitted. Other pronounced symptoms in advanced cases of silicosis were constipation, epigastric discomfort, and other vague complaints which the men termed "indigestion." The causes of the gastrointestinal symptoms were not ascertained.

Sayers (120) summarizes the clinical findings in silicosis as follows:

> The practically constant clinical signs are: A certain lack of elasticity of the chest wall during the movements of respiration, together with a somewhat reduced air entry, and a characteristic alteration of the inspiratory murmur from the normal "vesicular" character to a higher pitched or "harshened", "thinned", and commonly somewhat shortened type, the expiratory murmur, although somewhat prolonged, remaining fainter than the inspiratory.
>
> This type of breath sound is very characteristic, with some modifications, of silicosis in all its stages, and this clinical sign has also the significant character of more or less complete generalization. It is first noticeable at the anterior, lateral, and basal regions.
>
> In the minority of cases, however, the breath sounds may be simply diminished, but breath sounds which are simply diminished, or which, on the other hand, are merely somewhat louder or more "pronounced" than normal are not specially characteristic of silicosis.

Usually there are no accompaniments, but a stray ronchus may be heard here and there.

This complex of physical signs is almost constantly present in cases of a slight degree of "simple" silicosis. The cough may be put down to the coincident bronchitis and bronchiolitis, the recurrent pains to slight intercurrent local pleurisies.

Pathology

According to Pancoast (22) the pathological features of pneumoconiosis are (a) entrance of dust; (b) "dust cell" or macrophage; (c) entrance of the dust cell into the lymphatic system of the lungs as a carrier of silica or other particles; (d) influence of the deposited silica in the production of fibrous tissue; (e) action of silica; (f) elimination of dust; (g) predisposition of the fibrotic and silica-saturated lung to respiratory infections, especially tuberculosis.

The lung, as described by Gardner (121), is an organ developed to permit an interchange of gas between the blood and the external air. As it is in free communication with the exterior it is more or less exposed to the action of atmospheric impurities, both particulate and gaseous. Certain mechanisms are provided to protect the lungs from the accumulation of such foreign particles. The nose, through which the respiratory tract opens onto the surface of the body, is guarded by a coarse filter of hair. Behind this is a series of tortuous passages with moist walls which trap many smaller particles. In addition, the nasal cavities and the remaining portions of the upper respiratory tract, the pharynx, the trachea, and the bronchi are lined by cells covered with minute vibratory hairs, the cilia. Wavelike vibrations of these hairs tend to carry particles lodging on their surface away from the lung and back toward the surface.

Particles that succeed in passing these barriers and penetrate to the terminal air spaces of the lungs are ingested by wandering scavenger cells or phagocytes, which come from the partitions between the spaces for the purpose. These cells are capable of independent movement and tend to carry the foreign particles out of the air spaces into a special drainage system known as the lymphatics. The lymphatics are minute vessels, which drain into sedimenting basins known as lymph nodes. They are situated along the course of the vessels and bronchi and at the root of the lungs where the trachea divides into the two main bronchi. For ordinary amounts of atmospheric pollution these protective mechanisms are adequate to prevent the significant accumulation of foreign particles in the functional part of the lungs. If a person continues to work in a very dusty atmosphere for long periods his protective devices cannot cope with the situation, the mechanisms themselves are damaged, and the dust particles collect where the air should be (121).

According to Simson (122), if the first line of defense is passed and particulate matter reaches the alveoli, the cells lining the alveoli are stimulated to activity. They swell, become detached from the walls, and

develop an active phagocytic function. The particles are phagocyted and are then carried in 1 of 2 directions; some of the phagocytes, now laden with dust, pass to terminal bronchioles, whence they may be removed in the sputum; others pass into the walls of the vestibules and terminal bronchioles. In time large numbers of dust-laden cells accumulate and cause condensation of the tissues about the entrance to the primary unit. During the period of excessive dust inhalation and possibly for a short time afterward dust cells are continually reaching and entering the areas of condensed tissue at the entrance to the primary unit. Although some cells are arriving others leave the condensed areas and enter the regional lymphatic vessels, along which they pass to the minute masses of lymphoid tissue which lie between branches of the pulmonary artery and the adjacent bronchioles, vestibules, and atria. The presence of the dust cells stimulates the lymphoid tissue and causes it to become hyperplastic. With continued arrival and accumulation of dust cells in the lymphoid masses more or less well-defined aggregations are formed. The site of an aggregation can retain only a limited number of dust cells, so that with new arrivals an overflow results. The cells comprising the overflow and those that have escaped arrest pass onward in the peribronchial and perivascular lymphatic vessels, finally to be trapped in the lymph nodes at the root of the lung. In silicosis these lymph nodes are the first sites to show fibrosis.

If inhalation of injurious dust other than silica - for example, asbestos dust - is continued over a long period or over a shorter period when the concentration of dust is great a diffuse, cellular fibrosis develops in the walls of the bronchioles, vestibules, and atria. The fibrosis tends to extend locally, involving the supporting connective tissue of the adjacent blood vessels and to some extent the walls of the alveoli in the immediate neighborhood. There is usually desquamation of the epithelial lining of bronchioles and vestibules, often without evidence of a definite exudate. In very advanced cases the fibrosis may extend to the septa, to the supporting tissues of the bronchi and larger blood vessels, and to the alveolar walls. Even in these cases fibrosis is localized to the supporting tissue about the entrance to the primary unit. It may advance to such an extent that the bronchioles become constricted, sometimes retaining their circular outline in cross-section and sometimes being reduced to mere slitlike openings. Rounded nodules of cellular character occasionally are seen, but the dense hyaline type of nodule usually is absent. Dust containing only a small percentage of silica also may produce these changes, and the liability to generalized fibrosis is greater when a low-grade type of infection (not necessarily of tuberculous origin) complicates the dust effect.

The changes described above by Simson (121) appear to him as primary lesions caused by inhalation of any injurious dust, but when the great majority of the inhaled particles is composed of or contains silica a specific and localized type of fibrosis - the silicotic islet - also develops. The first evidence of the specific and localized lesion, which Simson (121) termed the "silicotic islet", is seen in the aggregation of dust cells that probably represents the site of the lymphoid mass. A small, round area of fibroblasts appears in the center of an aggregation; on further development a central core

of dense, fibrous tissue is formed. It often becomes hyaline in character and in larger and older nodules takes on a whorled arrangement. A fully formed single silicotic islet consists of a central mass of dense hyaline fibrosis arranged in whorls and surrounded by a comparatively narrow zone of cellular fibrosis in concentric laminae. Scattered through this mass, lying between connective tissue cells and fibrils, are scanty large and small round cells and a little particulate matter. A deposit of fat may be seen also in suitably stained sections, the degree varying with the age of the nodule. The early fibrotic nodule thus formed is surrounded by numerous dust cells. The growth of the silicotic islet continues by successive new arrivals of dust cells and subsequent extension of the fibrosis at the periphery of the fibrotic nodule. Apart from the individual single or composite palpable islet, noninfective silicosis may appear as a "massive" type of fibrosis. Seen microscopically, such lesions comprise numerous contiguous single and composite islets. The fibrosis is of the same character as that of the single islet; there is no evidence of breaking down. The intervening alveolar tissue is much compressed and collapsed, but there is no evidence of inflammatory infiltration or of definite matting together of the individual islets. As a rule, the larger blood vessels are not constricted.

These changes, according to Goodrich (100), make the lungs less elastic, increase their bulk, make aeration of the blood less efficient, and decrease circulation through the lungs. As a result, a more vigorous respiratory effort is necessary to supply the blood with an adequate amount of oxygen and to remove the accumulated carbon dioxide in the blood. An increase in inspiratory effect is needed to create greater negative pressure within the chest in order to draw into the less elastic lungs the same amount of air, and an increase in the normal tidal volume is needed because of the decreased areation of the damaged alveolar structures and the impaired circulation through these alveoli. As the volume of the lungs increases from the continuing deposit of silica and the increasing amount of fibrous tissue the chest gradually is held and later fixed in a position of partial inspiration, and breathing becomes more and more diaphragmatic. Even diaphragmatic breathing eventually becomes less efficient because of the usual development of a basal pleurisy which causes the inelastic lungs to adhere to the upper surface of the diaphragm. Secondary infection with bacteria may cause still greater lung damage. Chronic bronchitis or bronchiectasis may be caused by streptococcus, staphylococcus, pneumococcus, or other pyogenic organisms, as evidenced by investigations of the United States Public Health Service (123) on the development of pulmonary infections in pneumoconiosis. The results of the bacteriologic and experimental study show that -

> In general, the silicotic lung is more susceptible to bacterial infection than the average lung. This is probably due to the irritation of the respiratory tissues by the inhaled dust particles which weakens the mucous membranes and renders them susceptible to infection. The toxic influence of certain inorganic dusts upon the tissues may be a contributing factor.

The relation of tuberculosis to pneumoconiosis has been studied to a considerable extent, but comparatively little work has been done in

connection with other infectious processes of the lung, e.g., pneumonia, lung abscess, bronchiectasis, and influenza. An investigation was made of these conditions, both bacteriologically and experimentally, with the view of obtaining a better understanding of the predisposition to, and the mechanism of, infection of the lung in certain dusty trades.

Bronchiectasis, lung abscess, and gangrene occur frequently in hard-rock miners. It has been definitely established that aerobic, pathogenic bacteria, and certain fungi are responsible for these conditions, but the high percentage of cases in which the anaerobic microbes of the mouth and throat have been reported would suggest that they at least participate in the etiology of the diseases.

According to Tillson (124) many of the phagocytes of the lungs, when carrying mineral particles, become trapped in the lymph channels and nodes and therefore are not eliminated. Those free in the blood stream are charged positively at the hydrogen-ion concentration of the blood and move to the cathode in an electric field. Bacteria carry a negative charge and therefore are attracted to the phagocytes, are adsorbed, and then ultimately absorbed. The agglomeration of bacteria increases the efficiency of this process, as the large phygocyte cell can dispose of many bacteria in one contact. This clumping of bacteria depends upon the plasma salts being at a high enough concentration; otherwise, bacterial absorption becomes a slow process.

Silicosis is a progressive disease. If enough silica has been inhaled to initiate nodule formation each focus continues to enlarge until a state of equilibrium is established. Nodules not visible by X-ray when a men leaves a silica industry may subsequently increase enough in size to be readily detectable some years later. The progression of the process is favored and accelerated by the development of pulmonary infection (121). In fact, many pathologists doubt whether the fibrosis of the lung that constitutes the essential pathological nature of silicosis ever arises independently of a primary infectious process (125). Rist, Mayel, and Donbrow (126), after studying the question from the medico-legal point of view, are convinced that silicosis cannot develop other than in persons already infected with the tuberculous virus and hence refuse to regard silicosis as a true occupational disease.

In some cases the infection remains latent, presents none of its usual manifestations, and merely modifies the character of the reaction to inhaled silica dust. In others it develops simulataneously with the silicotic reaction with a more or less typical localization in the upper part of the lungs. Such cases may exhibit none of the characteristic symptoms of tuberculous intoxication for many years and often are discovered only in routine roentgenographic examinations of large groups of active employees. Ultimately these men develop symptoms, expectorate tubercle bacilli, and finally die of tuberculosis, but the course of their disease is protracted. There are still others whose roentgenograms show so much evidence of tuberculosis that the characteristic features of silicosis are obscured. Nevertheless, they have long been exposed to dust, and post-mortem examination will reveal the nodular fibrosis produced by silica. Like those of the preceding group, these cases run a

definitely chronic course and may not die of their infection until the fifth or sixth decade. Finally, there is another group, with well-developed nodular silicosis, whose members apparently have never had a tuberculous infection. Such men become infected, develop a rapidly progressive tuberculosis, and die within 6 months. In them the symptoms of intoxication are more acute, but bacilli may be very difficult to detect in their sputa and even in the lungs removed at autopsy (121).

Gardner claims (121) there is no difficulty in demonstrating that silica produces a reaction in the body specifically favoring multiplication of tubercle bacilli. Kettle injected a definite quantity of fine silica particles beneath the skin of one flank of a white mouse and in the opposite flank the same quantity of aluminum oxide particles. A large dose of tubercle bacilli was then injected into the tail vein of the animal. The blood distributes these bacilli quite uniformly to all parts of the body, but if the animal is killed after several days large masses of them will be found at the site of the injected silica. The bacilli are no more numerous where the alumina particles have localized than in any other part of the body. Apparently the reaction induced by the silica produces a favorable medium for the growth of these bacteria, but they disappear later and may be very hard to find. The same seems to be true of the sputum of men with silicosis and tuberculosis.

Gardner (121) reiterates that only silica and a limited number of the silicates are known to produce definite and serious pulmonary damage. In the case of silica this is associated with specific indisposition to tuberculosis and pneumonia. Of the silicates asbestos is definitely recognized as a cause of pulmonary fibrosis. Its importance in predisposing to tuberculosis is not yet settled.

At the International Conference on Silicosis (119) it was agreed that the microscopic pathological changes that may be produced by the prolonged inhalation of silica dust are:

(a) The development of a condition designated in South Africa as a dry bronchiolitis, characterized by an accumulation of dust-filled phagocytes in or in relation to the terminal bronchioles, with possibly some desquamation of their epithelium.

(b) The accumulation of dust-containing phagocytes about and in the intrapulmonary lymphoid tissue and their transportation through the lymphatics into the tracheobronchial lymph nodes. (The conditions described above under (a) and (b) do not constitute the disease silicosis.)

(c) The gradual development of fibrous tissue within such accumulations of phagocytes and the formation of characteristic nodules of hyaline fibrous tissue.

(d) Degenerative changes in these foci.

(e) The hyaline nodules increase in size by extension of their periphery. Coalescence of adjacent nodules takes place and brings about involvement of further areas of the lung. (The conditions described under (c), (d), and (e) constitute the disease silicosis.)

Macroscopically the changes observed in silicosis are:

(a) In the early stage.- A variable number of palpable pearly-white nodules up to 2 or 3 mm in diameter on the pleural surface of the lung. On section, the cut surface of the lung is studded with pigmented foci, widely scattered, a moderate proportion of which are only just palpable. The tracheobronchial lymph nodes are slightly enlarged and deeply pigmented and may exhibit foci of fibrous induration.

(b) Later stages.- The fibrotic nodules are increased in number, size, and density, and coalescence of these may be found. The portion of the lung between the fibrotic nodules may be emphysematous. The tracheobronchial lymph nodes may be smaller in size than those seen in the early stage and are fibrosed.

It was also agreed that the presence of tuberculous infection usually modifies the pathological appearance, and special attention was drawn to the following three types:

(a) In which the picture of silicosis above described may be little, if at all, modified, but in which only a biological test can demonstrate the presence of B. tuberculosis.

(b) In which the coexistence of silicosis and typical tuberculosis lesions is easily recognizable.

(c) In which the presence of tuberculosis is easily recognizable, but the existence of silicosis is more difficult to determine.

In massive silicosis cardiac hypertrophy and subsequent dilatation may occur. In silicosis with infective processes cardiac changes may also occur. No evidence was adduced in regard to involvement of kidney or liver.

Stages

The Committee on Pneumoconiosis and the Committee on Standard Practices in Compensation of Occupational Diseases of the American Public Health Association in a report on silicosis (127) described the stages of the disease as follows:

The disease is divided arbitrarily into first, second, and third stages for convenience of description and possible compensation purposes.

<u>First stage (corresponds to anteprimary stage of South Africa)</u>.- The symptoms of uncomplicated first-stage silicosis are few and often indefinite. The man may apparently be quite well and his working capacity not noticeably impaired. Slight shortness of breath on exertion and some unproductive cough, often with recurrent colds, are the most usual symptoms. The man may have a little less ability to expand his chest than formerly and the elasticity of the chest may be slightly impaired. The earliest specific indication of the presence of silicosis is the radiographic appearance, consisting of generalized arborization throughout both lung fields with more or less small, discrete mottling.

This characteristic mottling is due to shadows cast by the discrete individual nodules of fibrous tissue in the lungs and is essential to the diagnosis of silicosis; without this finding the diagnosis of silicosis is not sustained except by autopsy.

<u>Second stage (corresponds to primary stage of South Africa)</u>.- A definite shortness of breath on exertion is usually found, and pains in the chest are a frequent complaint. A dry morning cough is often present, sometimes with vomiting, and recurrent colds are more frequent. Even then the man's appearance may be healthy but he is dyspneic on exertion, he cannot work as well as formerly, his chest expansion is noticeably decreased, the movement being sluggish and diminished in elasticity.

The characteristic radiographic appearance is a generalized medium-sized mottling throughout both lung fields. The shadows of the individual nodules are for the most part discrete and well defined on a background of fibrous arborization, but there may be here and there larger but limited opacities due to irregular pleural thickening or to a localized aggregation of nodules.

<u>Third stage (corresponds to the secondary stage of South Africa)</u>.- In the third stage the shortness of breath is marked and distressing even on slight exertion. The cough is more frequent; the expectoration is in most cases slight but may be copious. The individual's capacity for work becomes seriously and permanently impaired; his expansion is greatly decreased even with forced inspiration; he may lose flesh; his pulse rate may be increased, and his heart may become dilated.

The radiographic appearances in the third stage are further accentuated, the mottling is more intense, the nodules are larger and take on a conglomerate form so that large shadows are shown corresponding to areas of dense fibrosis.

Physical examination of an individual may reveal changes in percussion and auscultation, mild in the first stage and increasing with the progress of the disease. These alone are not sufficient to be of great value in diagnosis of silicosis.

Pancoast and Pendergrass (128) question the wisdom of designating any appearance of pneumoconiosis by any term denoting numerical stages of progress. They prefer to designate the appearance by a term which implies its pathological nature:

> Now this appearance of prominent hilum shadows and increased prominence of trunk shadows and linear markings, with or without the faint haze, has in this country at least been designated as the first stage of silicosis or pneumoconiosis. There may be some excuse for continuing to call this the first stage, but continued experience with cases of pneumoconiosis developing in various industries has led us to question the wisdom of designating any appearance of pneumoconiosis by any term denoting numerical stages of progress. * * *. We prefer to designate the appearance by a term which implies its pathological nature and to call it not a stage but the perivascular-peribronchial-lymph node type or preponderance of the condition. * * *.
>
> In cases with silicosis which is moderately slow in its progression the microscopic nodular lymphoid deposit proliferations tend to become conglomerate and to produce a macroscopic nodular process * * *. As this appearance was found as a more advanced stage of silicosis in the earlier cases examined, and especially among miners in this country, it was and is still called the second stage of the condition. It is conspicuous by its absence or insignificance, however, in many industries, notably the granite cutter, sand-blaster, sandstone and asbestos workers. It is especially likely to be absent or inconspicuous in those who are developing silicosis rapidly, such as in those working with pulverized sand without adequate protection.
>
> If this appearance is absent or nearly so as a stage of progress in so many industrial silicoses, why designate it as a numerical stage of progress at all? We have ceased to do so, and have called this appearance the nodular type or preponderance of silicotic fibrosis, or, more correctly, silicosis.
>
> There is another type of silicotic appearance which was very puzzling to us at first because of its exact identity and our inability to find the proper place for it in a numerical classification of progressive stages. * * *. Fortunately a definite pathological place seems to have been found for the condition and a roentgenological classification for the appearance. * * *. We have designated this as the interstitial type or predominence and have subdivided it into rapid and slow, which subclassification must depend largely upon the physical factors and time of exposure. * * *.
>
> This type of fibrosis will almost invariably progress to the terminal stage with little or no appreciable nodular appearance. Care must be exercised in differentiating it from a chronic interstitial lung change resulting from pneumonia or continued upper respiratory infection as in the sinuses. * * *.

The condition responsible for this appearance in advanced form and of rapid development has been termed "acute silicosis" by Chapman and some others. * * *.

There are few if any arguments to be recorded in connection with the terminal stages of silicotic fibrosis. Instead of the <u>third stage</u>, we have preferred to call this aspect of the disease the <u>terminal diffuse fibrosis</u>. It is more or less incapacitating in practically all instances, and all too often completely so.

With respect to the classification of silicotic appearances based upon known pathological changes, Pancoast and Pendergrass (128) suggest the following in place of the old numerical stages:

1. Peribronchial-perivascular-lymph node predominance or type. This may be rapid or slow, usually the latter.

2. Early interstitial predominance. This may be extremely or moderately rapid, depending on the silica intake. It may or may not have an associated slight nodular appearance.

3. Advanced interstitial predominance.

4. Nodular predominance. Rapidly or slowly progressing.

5. Advanced diffuse or terminal fibrosis.
   Conglomerate nodular type.
   Interstitial type.
   Massive fibrotic type.

Diagnosis

According to the Silicosis (Medical Arrangements) Committee of Great Britain (109) silicosis can be diagnosed even in its early stages, but the diagnosis is not free from difficulty. For instance, the clinical signs of silicosis resemble to a great extent those of other chronic diseases of the chest; further, silicosis may be complicated by the presence of tuberculosis in any stage. Irvine (129) states that it is impossible to deduce a practical standard of diagnosis from accounts of the disease furnished separately by the pathologist, the radiologist, and the clinician. Clinical examination is obviously an essential factor in the decision in any individual case, since it provides important information otherwise not obtainable regarding the general and local condition of the patient, the degree of incapacitation, if any, and the presence or absence of complication by active infection or by disease of other organs; but in a disease like silicosis clinical evidence in many cases is inconclusive and may be misleading. Other means of diagnosis in the living subject are radioscopy, radiography, and in the last resort the pathological condition found after death. Radiography also has its limitations, as on the one hand not all forms of pulmonary fibrosis revealed by it, even in miners, are of silicotic origin, and on the other hand certain types

of radiograph, which do not show unequivocally "specific" signs of silicosis yet in certain circumstances may be regarded legitimately as affording evidence of the presence of a silicotic factor in the case. Accurate knowledge from which to formulate a reliable general standard of diagnosis can be obtained only by correlation of the results of pathological observation in a large number of cases with radiographs taken from the chests of the same individuals shortly before death and with the results of clinical examination made during life. The final adjudication in any individual case must always incorporate the additional evidence supplied by expert clinical examination, which indeed is frequently the deciding factor, particularly in borderland cases.

Sayers (120) includes under "clinical manifestations" those factors that can be ascertained from the individual having the disease - personal data, past history of diseases, occupation, present history, physical examination, and roentgen and laboratory observations. Levey (111) states that it is inadvisable to overlook any diagnostic medium in the early stages of silicosis. The importance of the serologic examination and the correlation of the physical examination with the past history is so great as to render all the steps of the complete examination of almost equal importance. Although it is frequently said that no diagnosis of silicosis can be made properly without roentgen-ray examination such examination must not be considered adequate, except in advanced stages. The examinations at the Picher Clinic (88) included collection of data on race, family history, personal history, past history of illness, occupational history, and physical, X-ray, and laboratory examination. A brief summary of some of the results of the examinations follows:

Family history.- The incidence of silicosis or silicosis complicated with tuberculosis was found to increase as the family histories of the men were classed as good, average, or poor.

Personal history.- The use of tea, coffee, or tobacco apparently has no relation to silicosis or tuberculosis; but after silicosis has developed, the use of alcoholic drinks and patent medicines increases decidedly; the men take these to alleviate the symptoms of silicosis so that they can continue work.

A study of age groups in published results of several investigations on silicosis shows that in the early years of the occupational life of those in dusty occupations the incidence of silicosis is low, but with increase in the age group, regardless of length of employment, it increases slightly up to about the age of 40, after which there is a marked increase. Age, therefore, has an important bearing on the occurrence of silicosis and should be considered in employing men for work in dusty atmospheres.

No correlation could be made between silicosis or tuberculosis and overcrowding in sleeping accommodations. The number of hours of sleep bore no apparent relation to silicosis or tuberculosis.

Past history of illness.- The data seem to indicate that all infectious diseases of childhood except diphtheria and scarlet fever probably decrease resistance to tuberculosis and silicosis. Picher is free from malaria, but many of the men reported they had had malaria in the past; among these men the incidence of tuberculosis and silicosis was comparatively high. Tonsillitis, especially if the attacks are recurrent, seems to be associated with tuberculosis but apparently has no relation to silicosis. The highest incidence of silicosis or tuberculosis, or both, was among men who reported bronchitis, pleurisy, and asthma. The lowest incidence was among those who reported influenza, pneumonia, coryza, and hay fever. An unknown and disturbing factor in the attempt to discover a relationship between silicosis or tuberculosis and other diseases was the difficulty in determining in many instances whether they occurred before or after silicosis and tuberculosis had been contracted. The data show that the incidence of physical defects increases among men with silicosis and tuberculosis. Several explanations are offered for this fact: Men with silicosis or tuberculosis usually are somewhat older than men in the essentially negative group; the silicotics have had a much longer period of service in the mines than the negative subjects; certain physical defects may increase susceptibility to silicosis.

Nasal obstruction and chronic catarrh, enlarged turbinates, adenoids, or other conditions that cause mouth breathing are associated with an increase in the incidence of silicosis. Persons having a vertical hanging heart are more likely to develop tuberculosis or already have it; this finding agrees with South African experience.

Occupational history.- A detailed statement of occupation is the most important single item in the history of silicotics. The mere statement that the man is a miner has slight value, if any. Many underground occupations expose the workmen to very little dust, especially in well-operated mines. The Picher histories included occupation before mining, past occupation underground, number of years in present occupation, kind of mineral mined, and total years in metal mines. All examined were divided into two groups according to duties - those exposed to large amounts of dust (those employed at the face) and those exposed to relatively small amounts (those away from the face). The data indicate that the men in certain positions contract the disease more quickly than those in other positions.

With the development of first-stage silicosis there was a drop in the number of weeks and shifts worked, and with second-stage silicosis there was a marked drop in amount of work performed on each shift. Men with silicosis and tuberculosis worked intermittently during 15 weeks of the year, while third-stage silicotics worked part of only 9 weeks; the number of shifts worked by these two groups, however, was almost the same (54 and 53).

Physical examination.- No marked symptoms of ill health, such as paleness, loss of subcutaneous fat, or decrease in muscular development, appear until silicosis reaches the third stage or until it is complicated with tuberculosis. Men with first- and second-stage silicosis appeared, on the whole, to be in better health than those in the essentially negative group.

As silicosis advances weight shows a slight tendency to increase until the third stage is reached or until the disease is complicated with tuberculosis. This increase may be due to some extent to the increase in age.

An analysis of systolic blood pressure by age groups shows that the blood pressure of the younger men did not change appreciably but that the average of the older men who had silicosis was slightly higher than for those in the corresponding age group who were essentially negative. Clinical observation shows that the blood pressure of silicotics tends to remain normal or increase only slightly, but in tuberculous cases it shows a definite tendency to drop. Any persistent marked drop in the blood pressure of silicotics indicates probable tuberculous infection.

It is generally accepted that the cardinal physical finding in silicosis is diminished chest expansion. Emphasis should be put not upon chest expansion but rather upon the importance of comparison with a man's earlier chest expansion. Probably if the vital capacity were taken on a large unselected series for comparison the decrease in vital capacity in silicosis would be greater than any chest-expansion measurements, however carefully taken, would indicate.

In the chests of miners generally, particularly those with silicosis, certain breath sounds rarely noted in the chests of healthy people not working in dusty occupations are often detected.

The slight changes revealed by examination of the heart probably could be attributed to the ages of the groups of silicotics.

Roentgenological Aspects of Silicosis

It is generally accepted that the X-ray offers the best and most reliable indication of the lung changes that occur in silicosis, particularly in the early stage. The value of this method of diagnosis depends largely upon the skill of the technician who takes the pictures and the experience of the reader who interprets them.

According to Pancoast and Pendergrass (130) the ability to interpret roentgenograms of cases of pneumoconiosis properly must be based upon several very important factors which may be enumerated as follows: A knowledge of the anatomy of the chest and many of the physiological problems associated with its anatomical constituents; thorough familiarity with normal roentgenographic and fluoroscopic appearances and permissible variations therefrom within normal limits; knowledge of the histology of the lungs and especially of the lymphatic system; clear perception of the pathology of the condition of pneumoconiosis and of all conditions which may simulate it in roentgenographic appearances; experienced intimacy with the roentgenographic appearances of the condition in question and of those that resemble it, based upon fundamental knowledge of the pathology represented; knowledge of the physical factors involved in the production of the suspected or alleged pneumoconiosis; and the employment of the proper technic to show to full advantage

any or all of the abnormalities present, for technic may fully enlighten, may so modify appearances as to be confusing, or may be quite misleading.

In a discussion of the X-ray findings of the Picher Clinic (88) the fibrotic changes revealed by the study are classified arbitrarily as definitely negative, more fibrosis than usual, decidedly more fibrosis than usual, three stages of silicosis, and silicosis plus tuberculosis.

Definitely negative.- In the definitely negative chest the hilum shadows are not more than $7\frac{1}{2}$ cm in width from the midline and do not cover more than 2 interspaces and 1 rib at a target distance of 48 inches. The hilum shadows occasionally may show one or more fairly large calcifications.

The pictures disclosed little if any evidence of an unusual amount of peribronchial thickening in any of the definitely negative chests. The bronchial tree usually cannot be traced farther than the inner edge of the mid-third of the lung and never beyond the inner section of the outer third of the lung. The areas between the shadows thrown by the bronchial tree are clear and show no evidence of any inflammatory changes.

More fibrosis than usual.- The hilum shadows are larger than normal - that is, more than $7\frac{1}{2}$ cm wide (from midline) - and cover more than 2 interspaces and 1 rib. Most of these cover more than 2 interspaces and 2 ribs. The calcifications within the hilum shadows show a very definite increase and sometimes are very large. The bronchial tree shows definite thickening and often extends well into the apexes. In the majority of cases its branches can be observed radiating to the outer third of the lung.

Decidedly more fibrosis than usual.- This class corresponds to that sometimes referred to as presilicotic. The hilum shadows are definitely enlarged and dense. The X-ray reading showed that 94.46 percent of these cases at Picher had large, dense, hilum shadows. The bronchial tree shows a definite thickening and extends to the periphery of the lung, involving the bronchioles and possibly the air vesicles.

First-stage silicosis.- The hilum shadows are increased in density and are larger than normal. In many instances (of Picher cases) large calcified spots were noted in or around the hilum shadows. These were larger than those generally observed as the result of tuberculosis in childhood. In several instances collections of such calcifications involved the entire hilum.

Following enlargement of the hilum shadows, the entire bronchial tree increases in density. It is very noticeable and often can be traced to the outer margins of the lungs. Along the thickened bronchial tree near the hilums are small shotlike spots, sometimes described as "beads" or bronchial "buds." When the spots become noticeable throughout the lower section of the lungs the case is classified as the beginning of first-stage silicosis. The spots are fairly dense, one eighth inch or less in diameter, discrete, with irregular fuzzy outline. With advance in the disease the spots increase in number, density, and size.

The diaphragm was humped in only a small number of the Picher cases in early silicosis, and no displacement of heart shadow as a result of the disease in this stage was observed.

Second-stage silicosis.- The hilum shadows are large and dense but generally do not show any more definitely than in first-stage silicosis. The beads or buds along the bronchial tree become larger, more numerous, denser, and clearer in outline; the condition is best described as a general "mottling." The mottling is bilateral, and the density is about equal on both sides, indicating that the changes started in both sides at or about the same time.

The diaphragm is often humped or "peaked", and numerous bands of adhesions are noted at the bases. The heart shadows usually are normal.

Third-stage silicosis.- The spots described under second-stage silicosis tend to coalesce, forming large areas of marked density. In some of the cases very large areas of marked density were observed - usually in the middle section of the lungs - which were similar to tuberculous consolidation; these areas, however, usually were bilateral and blended so perfectly with the snowstorm appearance as to suggest silicotic areas, which the physical examinations and laboratory findings tend to confirm.

Silicosis plus tuberculosis.- The ordinary silicotic findings described under the different stages of silicosis were noted in the Picher cases (88). In many of them detection of the beginning of tuberculous infection was difficult because of the extensive silicotic changes. The hilum shadows were more likely to show calcified spots than in uncomplicated silicosis. In some of the cases the calcified spots or glands were very large and occasionally occurred in large numbers.

With the beginning of tuberculosis areas of marked density were observed, usually at one or both apexes. These areas were not so dense or opaque as the fibrotic areas of silicosis and appeared cottony or wooly. Usually they were unilateral in the beginning but often became bilateral before death. In some instances these areas occurred in the midsection of the lungs opposite the hilum. Large areas of marked density may occur in this region, and it was difficult to determine by X-ray whether the area was a walled-off tuberculous abscess or a dense fibrotic area of silicosis.

Pancoast and Pendergrass (130) summarize the roentgenological phases of the condition, which they had described previously, as follows:

1. The perivascular-peribronchial-lymph node aspect is due to the relaying of phagocyted dust to the pulmonary lymph nodes and their subsequent enlargement and ultimate partial fibrosis to the gradual enlargement of lymphoid deposits along the course of lymph vessels and the subsequent thickening of these vessels and stasis of contents. This is characterized roentgenographically by increased prominence of the hilum and trunk shadows and linear markings. This appearance is by no means characteristic of pneumoconiosis alone, and even if it does indicate the

condition, the phase is absolutely not incapacitating. It, together with a barely perceptible appearance of macroscopic nodules, corresponds to the so-called first stage.

2. The nodular aspect is due to the gradual enlargement of lymphoid deposits and their coalescence into quite apparent macroscopic nodules symmetrically scattered throughout both lungs. This corresponds to the so-called second stage. It is conspicuously absent in many industries, especially when the silica intake is rapid.

3. The interstitial type of the condition results from a hilumward and pleuralward block in the lymphatics and the escape of dust phagocytes in large numbers into the interstitial interalveolar tissue and subsequent fibrosis. It appears as a faint homogeneous haze, first on the right side, then on the left. If the silica intake is comparatively slow, it may accompany the perivascular-peribronchial-lymph node aspect, but if more rapid, it may be associated with the nodular type or may progress without the latter directly into the terminal stage of the condition without any evidence of nodulation. The unprotected or inadequately protected sand-blaster, sand pulverizer, and sandstone abrasive worker or granite cutter have been among those especially prone to present this rapid interstitial aspect.

4. Terminal and incapacitating silicosis is characterized by three general appearances - a terminal diffuse fibrosis of a conglomerate nodular type, one which is quite similar in appearance to a generalized chronic fibroid tuberculosis, and the terminal stage characterized by large fibrous consolidated areas, which closely resemble tuberculous consolidations quite frequently, but which we are now learning to differentiate one from the other.

According to Gardner (121) anatomic and roentgenologic studies of the lungs of persons exposed to various types of industrial dusts have demonstrated that all inhaled foreign substances do not produce the same kind of pathologic reaction. He divides the forms produced into three catagories - linear, nodular, or diffuse in character. A linear pattern characterizes the general type of response to most inhaled inert foreign materials; nodular lesions apparently are confined to silicosis; and diffuse reaction is exemplified in asbestosis. Mixed patterns are produced by dusts such as granite, which is composed of several different elements.

According to Haldane (131) the diagnosis of silicosis, apart from a history of serious exposure to dangerous dust, is extremely difficult, and the sooner some sort of agreement can be reached as to the grounds for a diagnosis of silicosis the better; but these grounds must be consistent with known facts regarding the infrequency or frequency of phthisis in the kind of occupation in which the patient has been actually engaged - for example, ordinary collier's work or work in driving a road through highly siliceous rock without adequate precautions.

Smith (132) has pointed out striking discrepancies between symptoms and physical signs and pulmonary fibrosis as shown by the X-ray. In a study of rock drillers in the vicinity of New York 25 percent of those whose X-rays showed unmistakable silicosis had no symptoms whatever, and in a recent study of granite workers (133) in the same locality 6 cases of 17 with advanced silicosis had no symptoms. Absence of symptoms does not indicate absence of silicosis. Smith quotes an incident reported by Watkins-Pitchford; of a group of 541 miners who had been receiving compensation for silicosis on the basis of a physical examination alone 41 percent were found not to have it when X-rays were introduced. She considers a physical examination somewhat of a luxury where large groups of workers are being examined for silicosis; where economy of time and expense is desirable it would seem legitimate to limit the examination to a good roentgenogram supplemented by occupational history.

McNally (134) states that during life the diagnosis of silicosis depends on the history, clinical examination, and roentgenographic evidence of the disease. Many times the roentgenograms are not decisive, so the diagnosis of silicosis, silicosis plus tuberculosis, or tuberculosis cannot be made with certainty. At autopsy the doubt may still linger; then a chemical examination for the quantitative determination of silicon dioxide aids in reaching the correct diagnosis.

How Fibrosis of the Lungs is Produced

According to Kettle (118) silicosis presents to the pathologist two fundamental biological problems: What is the exact process by which fibrous tissue is formed in the lungs in response to the presence of dust and how does dust influence the progress of a coincident infection? He considers that these problems lie at the very root of the matter, and even if the answers were known he doubts whether we should be in a much more favorable position to deal with the situation as it exists in industries. "But", he says, "if we cannot explain the how of the matter we may still hope to speak with some authority about the when and the where. We can discuss with profit such questions as the identification of dangerous dusts; whether they act chemically or physically; the influence of their physical state on their action; the influence of associated dusts; and the relationship of dust to infection."

For many years it was held that fibrosis of the lungs characteristic of silicosis was produced in response to the irritation caused by the hard, sharp, quartz crystals; that is to say, the dust was believed to act mechanically. Kettle (118) thinks that this point of view has some merit, that it is natural to think that hard, sharp quartz particles would wound and tear the soft tissues of the lung; it is, of course, a commonplace of pathology that foreign bodies in the tissues excite a certain amount of reaction which is followed by the production of fibrous tissue. This fibrosis, however, is never extreme and is never comparable to the extensive fibrous tissue formations which are the recognized lesions of silicosis. In point of fact, if a harmless dust is inhaled in large enough quantities some of it remains in the lung and causes mild fibrosis by the mere mechanical irritation of its presence. This fibrosis is never severe enough to interfere with the function of the lung, and in its distribution, particularly in its amount, it bears no comparison to that seen in the silicotic lung (118).

Kettle (118) considers solubility a primary factor in the harmfulness of silica, and he believes that a perfectly insoluble substance is incapable of causing pneumoconiosis. Exactly how the dissolved silica acts in the production of fibrous tissue is not known. His suggestion that it acts chemically as a cell poison has been severely criticized, probably on the grounds that since silica enters into the composition of animal and vegetable protoplasm it cannot be a protoplasmic poison. His reply to this criticism is that phosphorus enters into the composition of protoplasm, yet people have been killed by phosphorus and others have been hanged for poisoning them. Peacock (135) in 1860 made the first report of a microscopic demonstration of silica in the lungs. In 1866 Schmidt (136) reported sand in the lungs of all persons - except the new-born - ranging from 4.2 to 17.3 percent of silicon dioxide in the ash. According to Woskressensky (137) the lungs of individuals whose occupations do not expose them especially to dust inhalation contain an increasing amount of silica in direct proportion to the age. He found that from 3.5 to 33.7 percent of the ash of the lungs was silicon dioxide, and in the peribronchial lymph glands the amount was much higher, ranging from 18.3 to 55.6 percent of the ash. McNally (134) gives the silicon content of the lungs of 8 persons working in dusty atmospheres as follows:

Case	Ash, percent	SiO_2 per gram of dried tissue, mg	Occupation
44	10.78	8.6	Millstone sharpener.
503	17.14	14.0	Stonecutter.
327	12.36	2.4	Machinist.
429	14.58	3.6	Engineering draftsman.
463	19.99	4.3	Coal miner, 25 years.
411	8.84	5.0	Stone-quarryman, 9 years.
300	8.46	26.0	Granite cutter.
446	5.59	10.9	Zinc miner.

McNally (134) also states that the lungs of tuberculous subjects contain somewhat more silicon dioxide than those of normal persons; this may come from inhalation or directly from the blood stream, as the blood of tuberculous subjects contains more silicon dioxide than that of normal persons. He quotes Collis to the effect that all clinical observations have shown that a silicotic patient is particularly liable to tuberculous infection and that the silicotic process continues to advance after complete withdrawal from exposure.

Goodrich (100) thinks that dusts are more injurious as their chemical composition differs from that of the tissues of the human body.

With regard to the sericite theory, Gardner (121) states that, although it is too soon to comment authoritatively on Jones' thesis, silicotic nodules can be produced experimentally without sericite. Petrographic analysis of the silica employed for the animal experiments made in the Saranac laboratory has excluded contamination with sericite.

In his report on a comparative study of the solubility of finely divided rock dusts in water, kerosene, and alcohol Myers (138) makes the following statement regarding siliceous dust:

> It will be noted in test 1 that the process of solution (in distilled water) of the 5 mg quantity of siliceous dust was gradual throughout the 28-day period, solution being nearly complete at the end of this time; while the 50-mg weight of siliceous dust did not dissolve after the first 24 hours. It is believed that the finest particles went into solution very rapidly and that there was enough of them in 50 mg to saturate the solution in the first 24 hours. The 5-mg weight containing many larger particles and only a tenth as many of the extremely fine particles as 50 mg, went into solution slowly, and the solution was not saturated until the entire amount was in solution which took between 21 and 28 days.

Heffernan (139) summarized his theory of the action of silica on the lungs as follows:

> 1. Silicosis is a result of the local action of hydrated silica upon the pulmonary tissue. This action is of a physicochemical nature, and the speed of its development, other things being equal, depends upon the rapidity with which fresh silical hydrosol is formed and brought into contact with pulmonary tissue.
>
> 2. Substances which favor the formation of silical hydrosol from silica, when added to the silica dust, accelerate the development of silicosis - for example, the alkalis. Substances which retard or prevent the formation of hydrosol from silica, or which coagulate the hydrosol when formed, retard or prevent silicosis - for example, carbon, coal dust, clays, and probably many other substances.
>
> 3. The action of silica in producing the nodular pulmonary fibrosis which we term "silicosis" has not been paralleled so far by any non-siliceous substance.
>
> 4. Silica is a normal constituent of plant and animal cells; its presence seems essential in certain tissues, and its absence from the food of the organism disastrous.
>
> 5. The study of the role of silica in biology suggests that many of the processes of cell metabolism belong to the realm of colloidal physics.
>
> 6. Some characteristic cellular phenomena are explained most simply by regarding the living cell as a polyphase colloidal system.

Kraut (140) found that the silicic acid content of the blood of various normal persons fluctuates between 1 and 3 percent of the sulphate ash but that the individual maintains his silicic acid content with great constancy.

The administration of easily resorbable silicic acid increases the silicic acid content of the blood many times the absorbed amount of silicic acid.

Lieb and Schadendorff (141) found the SiO_2 content of pathological lungs of silicon workers to be 0.3 to 1.46 percent if dried at 120° and 4.6 to 22.8 percent of the ashed tissue. Normal lung tissue showed values of 0.08 to 0.40 percent. The pathological findings corresponded with the analytical results.

In connection with the solubility of silica dust Haldane's (142) explanation of the large percentage of the silicate sericite which Jones found in the lungs he examined is that sericite is less soluble than free silica in the alkaline liquids of the lungs. Kettle mentioned (142) in this connection that crystalline silica when inoculated in the veins produces lesions but that amorphous silica does not. He also said that readily soluble silica and insoluble silica do not produce lesions but that between these two is a silica that "turns the trick." In 1929 Mavrogordato (143) gave as the cause of simple silicosis the reaction of the reticulo-endothelial system of the organ concerned to invasion by free silica, but dust phthisis, the clinico-pathological entity met in practice is superficially a variable disease. Beyond the external factors and the reticulo-endothelial system as an apparatus lies the man. Individuals vary in their ability to resist the dust they inhale. The amount of dust that can be recovered from a lung need bear but little relation to the extent or character of the lesions found.

It was agreed at the International Conference on Silicosis in 1930 (119) that:

To produce the pathological condition, silica must reach the lungs:

(a) In a chemically uncombined condition, although the dust inhaled may be either a natural mixture of silicon dioxide with other dusts, such as occurs in granite, or an artificial mixture, such as scouring powder.

(b) In fine particles of the order of less than 10 microns. There is no evidence as to the lowest limit of size in which the particles may be capable of producing the disease.

(c) In sufficient amount, and over a certain period of time; these two factors are reciprocal variants. The minimum of these two respective factors has not yet been determined.

Silica dust plays the dominant role in the production of silicosis, admixture of other dusts tending to modify the picture in the direction of that of other pneumoconioses, in some relation to the proportion of free silica inhaled.

There is experimental evidence that the solubility of silica in the tissues is an essential factor in the causation of silicosis.

According to Badham's summary (144) of the information supplied by various members of the International Silicosis Conference silicosis becomes noticeable after widely differing periods of exposure to siliceous dust, depending apparently upon:

1. The amount of dust inhaled.
2. The percentage of free silica contained therein.
3. The size-frequency (or fineness) of the particles inhaled.
4. The nature and sort of such other substances (including vapors and gases) as may be inhaled simultaneously or otherwise.
5. The powers of resistance of the individual concerned.
6. The presence or absence of a complication by an infective process.

In a discussion of the sericite theory as a cause of silicosis Irvine (145) stated that although it quite probably will become necessary to revise and widen the definition of the essential factors in the causation of silicosis, even so nothing in all this has significantly altered the general conception of silicosis as a definite pathological entity, which is readily identificable by the pathologist after death and which is adequately distinguishable during life by expert clinical and radiological examination, or the knowledge that this disease year by year produces many cases of incapacity or death. The position, he says, in these respects is not significantly affected by the present lack of complete knowledge regarding the exact constituents of a siliceous dust that may cause silicosis. In spite of considerable opposition from certain quarters, this view was accepted at the meeting of the International Labor Conference at Geneva, in June 1934, and the conference accordingly affirmed the international recognition of silicosis as an occupational disease and described it as "silicosis, with or without pulmonary tuberculosis, provided that silicosis is an essential factor in causing the resultant incapacity or death."

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INFORMATION CIRCULAR

MILLING METHODS AND COSTS AT THE CONCENTRATOR OF THE ST. JOSEPH LEAD CO., ATLANTA, IDAHO

BY

E. D. Gardner

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

MILLING METHODS AND COSTS AT THE CONCENTRATOR OF THE ST. JOSEPH LEAD CO., ATLANTA, IDAHO 1/

By E. D. Gardner 2/

INTRODUCTION

This paper is one of a series on milling methods being published by the United States Bureau of Mines.

Atlanta is in Elmore County, Idaho, about 80 miles from the railroad at Mountain Home, Idaho.

The concentrator is at an elevation of 6,000 feet and located in a timbered, well-watered region of relatively heavy snowfall. The snow, however, does not seriously affect local operations. The truck road to Mountain Home, which passes over a mountain range, is closed each winter from about November 1 to June 15. During this period concentrates are stored and bullion is shipped by airplane. Power is generated by a Diesel engine and by an auxiliary hydroelectric plant.

Gold is the principal metal produced; the ore also contains an appreciable quantity of silver.

The ore is mined by cut-and-fill and square-set methods and trammed directly from the haulage adit to the mill bins. It reached the bins before the sulphides oxidize appreciably. The concentrator has a capacity of about 225 tons per 24 hours. A crew of 20 men is employed in the mill; although the mill is operated 7 days per week, the men work only 6 days. An average saving is made of about 90 percent of the gold and 94 percent of the silver. About 75 percent of the metals is recovered as bullion from amalgamation plates; the other 25 percent is obtained in flotation concentrates.

The mill was built during 1931 and 1932 and began operation on February 1, 1932. Previous operators had treated the ore from the mine in an amalgamating and gravity-concentration plant. The improved recovery of the metals by flotation makes it possible to treat ores that could not have been handled profitably under the old conditions.

1/ The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from U.S. Bureau of Mines Information Circular 6836."

2/ Supervising engineer, U.S. Bureau of Mines Southwest Experiment Station, Tucson, Ariz.

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ORE TREATED

The ore consists of quartz containing disseminated fine crystals of arsenopyrite and pyrite. Crushed and altered granite is the principal gangue material. The gold occurs free and with the sulphides. An attempt is made to save all of the sulphides in the mill.

METHOD OF MILLING

Crushing

The flow sheet of the crushing section of the mill is shown in figure 1. The ore as brought from the mine is dumped through a grizzly, with a spacing of 8 inches between bars, into a 1,066-ton crude-ore bin. Oversize on the grizzly is broken by hammers. The proportion of oversize is small, as the ore is passed through the same size grizzly in the mine. The ore bin is of conventional construction, except the front, which consists of locally cut logs lined with plank. The ore is drawn from the bin by a Stephens-Adamson pan feeder, 36 inches wide and 5 feet 6 inches from center to center, to a grizzly with bars set 1 1/4 inches apart. The grizzly undersize goes to a bucket elevator, 51 feet between centers and with 6 1/4- by 14-inch buckets spaced on 18-inch centers. This elevator discharges onto a 4- by 5-foot St. Joe vibrating screen. The screen opening is one half inch; it is vibrated 1,200 times per minute. The undersize from the screen drops directly into a flat-bottomed, 600-ton, fine-ore bin. The oversize from the screen passes down a chute to a set of 14- by 36-inch, Joplin, gear-driven spring rolls. These rolls operate in a closed circuit between the elevator and the St. Joe screen. The grizzly oversize drops into a 24- by 14-inch, Blake-type, Carterville jaw crusher. The discharge from the crusher goes to a second set of 14- by 36-inch Joplin rolls and thence to the elevator.

The crushing plant is protected from tramp iron by a 39-inch 20-kva Cutler-Hammer magnet. This magnet is energized by the same motor-generator set which charges to Exide batteries used in the underground haulage. The crushing plant is driven by a 100-hp. motor, belt-connected to a line shaft. Crushing is done on two 5-hour shifts.

Grinding

The crushed-ore bin is provided with four gates in the bottom. An 18-inch belt feeder from each gate discharges onto a main belt feeder, which is driven by a 10-hp. motor and travels 71 feet per minute; this in turn empties into a Denver Equipment Co. automatic sampler. (See fig. 2.) The ore from the sampler is mixed with enough water to give a pulp density of 60 percent solids and then fed into a 4- by 12-foot Marathon ball mill running at 32 r.p.m.

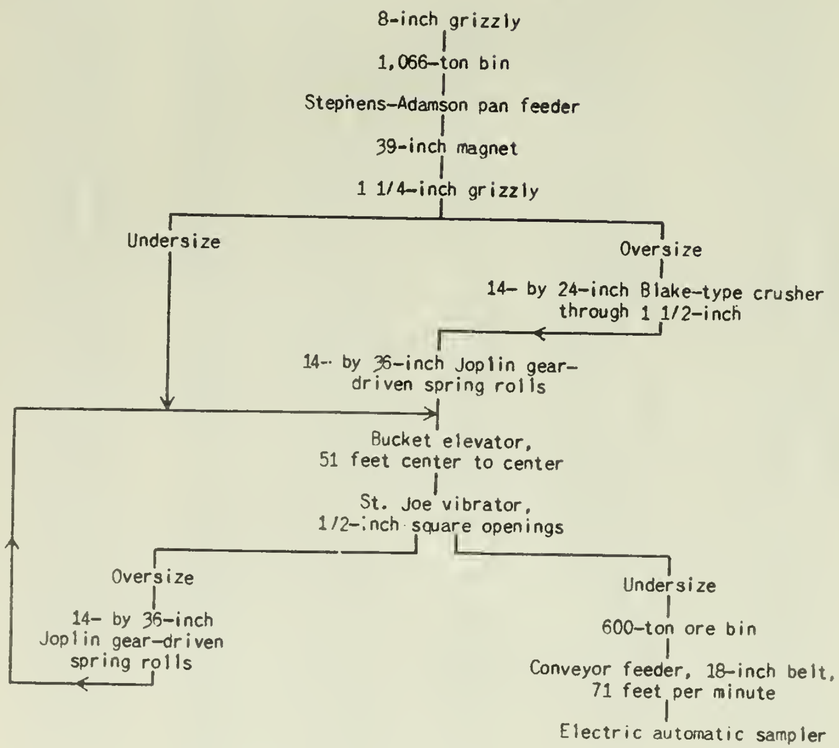

Figure 1.- Flow sheet of crushing section.

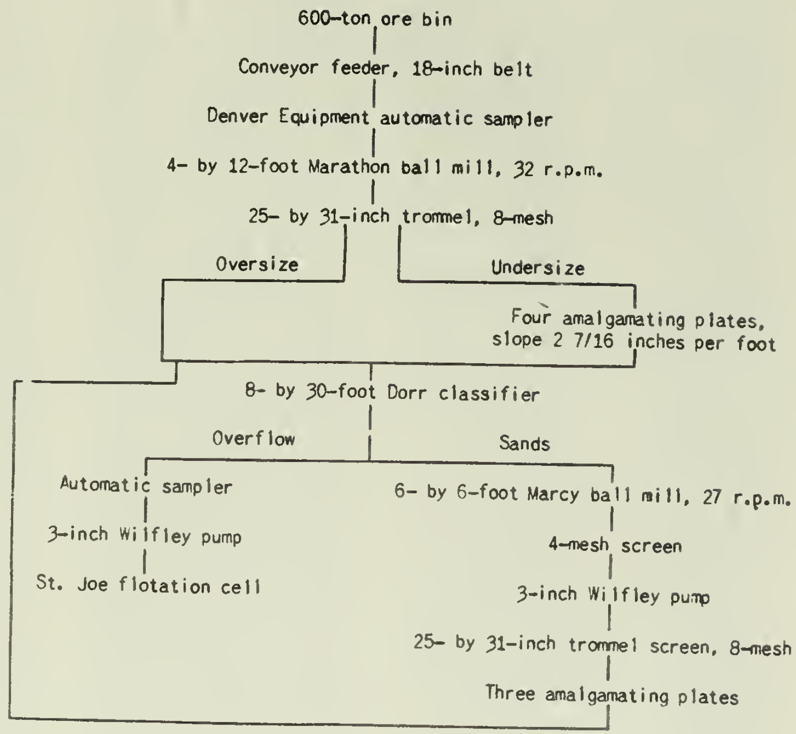

Figure 2.- Flow sheet of grinding and amalgamating section.

The mill which was originally designed for rods has been remodeled to use balls; the load is 12,000 pounds of drop-forged steel balls. Daily addition of steel balls are made to replace consumption. Equal weights of 4- and 3-inch balls are used in the mill.

The pulp is screened in a 25- by 31-inch, conical, 8-mesh trommel attached to the mill. The screen opening is 0.071 inch and the wire diameter 0.054 inch. The undersize, amounting to about 75 percent of the feed, passes over four amalgamation plates and thence to an 8- by 30-foot Dorr classifier; the oversize goes directly to the classifier. Six and eight tenths percent of the oversize is plus 4-mesh material.

The classifier is driven by a 10-hp. motor and is in closed circuit with a 6- by 6-foot Marcy ball mill which revolves at 27 r.p.m.; 5,000 pounds of 3-inch and 5,000 pounds of 2 1/2-inch forged steel balls are used; the circulating load is approximately 250 percent. The discharge from the Marcy mill goes over a 4-mesh screen and is then elevated by a 3-inch Wilfley pump to a 25- by 31-inch trommel with an 8-mesh screen, whence it passes over three amalgamation plates and back to the classifier. The overflow from the classifier, which was 80 percent minus 200-mesh, goes to a 3-inch Wilfley pump and thence to a flotation machine.

The Marathon and Marcy mills are driven by a 240-hp. synchronous motor with Medart V belt and a 12-inch, 5-ply belt drive.

Amalgamation Plates

The amalgamation unit consists of 7 plates, of which 3 are 4 feet 3 inches by 9 feet 6 inches and 4 are 4 by 7 feet in size. The slope is 2 7/16 inches to the foot.

The undersize of the screen on the discharge of the Marathon mill constitutes the feed to four of the plates. It is 100 percent minus 8-mesh, 3 percent plus 20-mesh, and 33 percent minus 35-mesh. The Marcy mill discharge is pumped back and put over the remaining three plates.

The cooling water from the Diesel engine is used in the winter to keep the temperature of the pulp going over the plates at a minimum of 45°F.

The plates are dressed one at a time every 2 hours. After the feed is diverted, a plate is washed with clear water from a hose. Quicksilver is applied to spots where the amalgam is hard. The plate is then brushed lightly with a dilute solution of ammonium chloride and the feed turned back on.

Quicksilver used for dressing the plates is cleaned with sulphuric acid to remove oil. An average of about 40 ounces is used for each dressing of the plates.

The amalgam is removed from the plates once each 24 hours. After the feed is shut off a plate is washed clean with water from a hose. Soft amalgam is scraped to the top of the plate with a section of rubber belting and taken

off with putty knives. Then the plate is washed with caustic soda solution and hosed off. Enough quicksilver is sprinkled on the plate to bring the amalgam remaining on it to the proper hardness.

About 200 ounces of amalgam from the previous day's clean-up is used in dressing the plates. Enough amalgam is applied to each plate to protect the plate surface from scouring and to aid in amalgamation of the gold and silver. This amalgam is cleaned with concentrated sulphuric acid then washed with water until no acid remains. After the right amount of clean amalgam has been applied to the plate, enough quicksilver to bring the amalgam to the proper hardness is sprinkled on and the plate brushed with ammonium chloride; the movement of the brushes makes distinct transverse riffles across the plates. The finished plate has a silver-white appearance and is now ready for use.

Traps

Traps 8 inches deep and with lengths equal to the width of the plates are used at the ends of the plates; they are cleaned up once each day. When the amalgamation unit is running smoothly 1/2 to 1 pound of quicksilver is caught in each trap daily. On rare occasions when the plates do not take the dressing properly, nearly half of the amalgam may be found in the traps.

Riffles

A 3-foot section of transverse riffles is placed in the main launder below the plates to catch any coarse or rusty gold and amalgam passing over the plates and through the quicksilver traps. The 24 riffles are made of 20-gage metal strips 1 1/2 inches high on 1 1/2-inch centers; they are tilted downstream. The riffles pack with sulphides, but the velocity of the pulp is sufficient to maintain a transverse hollow back of each riffle. The gold and amalgam are retained in the hollow. The riffles are cleaned up every 6 days, and about 5 pounds of concentrate is obtained.

Gold and amalgam are panned from the concentrate. The concentrate is then run over a laboratory amalgamation plate, the gold removed, and the balance put into concentrates. The pyrite is usually cemented and rusty and the quicksilver foul.

Six tenths pound of copper sulphate, 2.0 pounds of soda ash, and 0.01 pound of potassium-xanthate per ton of ore are added to the Marcy-mill discharge. The presence of these reagents on the three plates amalgamating the Marcy discharge has increased the amalgamation recovery.

Treatment of Amalgam

The amalgam, cleaned daily from the plates, together with amalgam from traps and riffles, is ground 3 hours in a Stearns-Rogers laboratory ball mill with hot water and enough quicksilver to make the amalgam soft. The ground amalgam is then washed with hot water and cleaned with a magnet until all the metallic iron and sulphides have been removed. The amalgam is then wiped dry with cloths. Two hundred ounces is set aside for platedressing the following

day; the remaining amalgam is squeezed in an amalgam press. This squeezed amalgam is very hard and contains from 58 to 65 percent of quicksilver.

The compressed-air press, which consists of a 3-inch pipe 13 inches long, is capped on both ends. One-eighth-inch holes spaced one fourth inch center to center have been drilled in the lower cap. The amalgam is placed on two thicknesses of muslin (see fig. 3) lying on a 60-mesh wire screen, which in turn is on the lower cap. Air at 100 pounds per square inch pressure is introduced through a 1/4-inch pipe tapped into the press near the top; the moisture and oil in the air pipe is blown out through a by-pass valve before the air is used in the press.

Retorting

The clean-up is retorted once a week in a no. 14 retort. The fire box in which the retort is heated is 12 by 14 inches; the bottom of the fire box is 10 inches from the bottom of the retort. Crude oil is used for fuel; a Denver fire-clay no. 250 centrifugal fan supplies the draft. A 3/4-inch pipe extends from the retort to a 2 1/2- by 36-inch condenser.

About 1,400 ounces of amalgam is treated and about 560 ounces of sponge bullion obtained. The sponge is melted in a no. 50 graphite crucible with 5 pounds of soda ash, 2 pounds of borax, and 1 pound of silica in an oil-fired furnace. The length of time required to make a fusion is 4 hours. The bullion is poured into a 4 1/2- by 4- by 11-inch cast-iron mold. The bricks weigh 830 to 880 ounces. The slag is broken up and fed to the Marcy mill.

Each bullion bar is sampled by drilling two 3/16-inch-diameter holes halfway through the brick on the center line and 1 inch from the ends on opposite sides of the bar. The sampling checked almost exactly with results from the United States assay office at Boise, to which the bullion was formerly consigned.

The bars range from 500 to 560 parts of gold per 1,000, usually near the latter figure. The total fineness of gold and silver is about 980; the impurity is principally speiss and metallic arsenic. The bullion is shipped each week by first-class mail to the mint. Postage, insurance, and mint charges total 8 cents per ounce. The amalgam and gold are insured from the time they leave the mill building proper. A watchman goes through the mill hourly; no other precautions against theft were taken in the mill.

Flotation

The classifier feed goes to a 3-cell St. Joe flotation machine. The first cell, 42 feet long, is a rougher; the second, 5 feet long, a cleaner; and the third, 2 1/2 feet long, a recleaner. The feed enters at one end of the first cell; the concentrate from the first 14 feet flows to the second cell, which in turn delivers its concentrate to the recleaner. (See fig. 4.) The rejects from the last two cells, together with the middling from the first cell, are returned to the head of the first cell by a 3-inch Wilfley pump run by a 10-hp. motor. The tailing from the rougher goes to waste.

The flotation feed is 80 percent minus 200-mesh and contains 27 percent solids. Tests show that an improved recovery does not result from finer grinding.

The three cells are in line and are supplied with air from a 16-inch pipe under a pressure of seven eighths inch of mercury. The branch lines leading down into the cells are 4 inches in diameter and 9 inches apart. The orifices at the bottom of the branch pipes are five sixteenths inch in diameter. Pressure is supplied by a 27-hp., General-Electric-type, F.S. 355, centrifugal compressor that ran at 3,500 r.p.m.

Mill slop is collected in a 5- by 12-foot circular sump, whence it is returned to the classifier every 2 weeks by means of a sand pump. An overflow of water from the sump carried away most of the lubricating oil.

Reagents

As mentioned before, 2.0 pounds of soda ash, 0.6 pound of copper sulphate, and 0.01 pound of potassium xanthate are added to the Marcy-mill discharge. Eighty-four thousandths (0.084) pound of cresylic acid, 0.017 pound of pine oil, 0.13 pound of Barrett no. 4 creosote, 0.064 pound of potassium xanthate, and 0.067 pound of aerofloat no. 25 are added to the flotation circuit ahead of the 3-inch Wilfley pump. The soda ash (10-percent solution) is prepared by agitating the salt in hot water by means of compressed air until it dissolves. The reagents are added to the pulp by Denver Equipment Co. bucket feeders.

Filter

The flotation concentrate goes to a 6-foot, 3-disk, Oliver-United filter run by a 7-hp. motor. A 9- by 12-inch, Ingersoll-Rand, vacuum pump run by a 25-hp. motor at 200 r.p.m. maintains a vacuum of about 18 inches of water. Cake from the filter drops directly upon a drier, which consists of hot plates heated by the exhaust gases from the Diesel. The concentrate is sacked in 130-pound bags and placed in storage.

Flotation Concentrate

The concentrate is shipped during the summer to Garfield, Utah. The rate for smelting is a flat charge of $5 per ton of concentrates. There are no penalties or bonuses charged against this concentrate.

TAILINGS DISPOSAL

The tailing is conveyed through a 500-foot launder to a 1,000-foot ditch leading to three settling ponds built one below the other in a gulch. Only one pond is used at a time. The overflow from the ponds goes to a clarifying pond with an area of about 300 square yards. The water as it leaves this pond is slightly "milky." The dams were started by laying 3 to 4 rows of round-timber cribbing across the bottom of the gulch and then filling in with sand from the tailing.

SAMPLING

Automatic samples are taken of the mill feed as it comes from the fine-ore storage bin, of the classifier overflow, and of the mill tailings. The pulp samples are obtained by means of Denver Equipment Co. motor-driven samplers that take cuts every 12 minutes.

All samples, both from the mine and mill, are prepared for assaying in the mill. The equipment consists of 1 Denver Clay 4- by 6-inch crusher, 2 Braun pulverizers, and 1 air-pressure filter. The sample room also contains a Ro-Tap screen for making screen analyses of the mill products.

A close assay control is maintained in both the mine and mill. An average of 45 samples is assayed daily for gold and silver. Six samples from the mill are tested for metallics, and three are run for insolubles each day.

POWER

Power is supplied by an 8-cylinder, 360-hp., Diesel engine (6,000 feet above sea level) and an auxiliary hydroelectric plant. The Diesel is of the type used in German submarines; it was purchased in Germany. No American manufacturer could make delivery of a Diesel plant during the summer the mill was being built in time to get it to the property before the roads closed for the winter. The engine is direct connected to a 375-kva, 3-phase, 60-cycle, 480-volt, Westinghouse generator that runs at 360 r.p.m.

A supply of extra valves and valve stems are kept in stock. Other repair parts are made in the mine shops by the chief Diesel operator who is a machinist.

The winter supply of fuel oil for the Diesel is brought in before the roads are closed and stored in a 108,000-gallon tank. The oil is filtered through a 3-ply filter pack before it goes to the engine. After the filter had been installed no trouble was experienced with nozzles choking as before.

The plant is run by a mechanic and two helpers on day shift and by one operator on each of the other two shifts. The two helpers spend about one half their time in the shops and one half in the mill. The mine air compressor is in the Diesel building and is operated by the Diesel crew.

The hydroelectric plant, consisting of a very old model Ingersol turbine wheel and a 125-hp. generator, is on the Middle Fork of the Boise River about 2 1/2 miles from the mill. During low water the capacity of the plant is reduced to 40 hp. The head on the wheel is 60 feet. The current is transmitted at 2,200 volts. Both plants are synchronized; switchboards and synchronizing apparatus are in the Diesel engineroom.

The connected load of the mine and mill is 353 hp. The average horsepower used for the different departments of the mill is shown in the following table:

Average horsepower used (voltage, 440)

	Horsepower
Crushing	41
Fine grinding	135
Flotation	37
Filtering	7
Miscellaneous	10
Total	230

The mill building was heated during the winter by the exhaust gases from the Diesel engine.

WATER SUPPLY

Water from a local stream is flumed along the mountainside into a series of 18- by 22-foot tanks at a point 150 feet above the mill. The mill is supplied through one pipe line; a second line provides fire protection to the mill and other camp buildings. Approximately 85 to 100 gallons of water is used per minute in the mill.

TRANSPORTATION

The concentrates are hauled 85 miles to the railroad during the summer months. Freight is hauled from the railroad to Atlanta on the return load. Heavy supplies, including fuel oil, are hauled to the mine during the summer and stored for winter use.

The minimum freight rate on ore from Mountain Home to Salt Lake Valley smelters is $2.75 per ton. The rate on high-grade concentrates is about $28 per ton.

During the winter Atlanta is served by an airplane company which brings in mail and supplies and carries passengers; six trips are made each week. The company built and maintains the landing field. A rate of 5 cents per pound is charged for bringing in supplies. The passenger fare is $20 per round trip or $10 one way. Special trips cost $40. The distance from Boise, Idaho, is about 60 miles; 30 to 40 minutes is taken for the trip. The plane used has a carrying capacity of 2,000 pounds.

LABOR

The wage scale in May 1934 was as follows:

Amalgamators	$5.50
Flotation operators	5.50
Ball-mill operators	5.00
Filter operators	4.50
Laborers	4.50

The company runs a boarding house for single men. Board and room cost $1.25 per day. Men with families live in the village of Atlanta about a mile from the mine.

PLANT RECOVERY AND COSTS

Metallurgical data are given in table 1, screen sizes in table 2, operating data in table 3, and operating costs in table 4.

TABLE 1. - Metallurgical data of the Atlanta mill, April 1934

Head assay:		
Gold	Ounces per ton	0.467
Silver	do	1.541
Total tons treated		6,575
Hours operated per day		24
Recoveries:		
Gold	percent	89.55
Silver	do	94.58
Recoveries by amalgamation		70
Recoveries by flotation		30
Concentration ratio		55
Tailing assay:		
Gold	ounces per ton	0.04
Silver	do	.085
Concentrate, weight	tons	119.75
Concentrate assay:		
Gold	ounces per ton	5.703
Silver	do	61.63
Insoluble	percent	15.0
Lead	do	.3
Copper	do	.3
Arsenic	do	6.0
Iron	do	38.0

TABLE 2. - Screen size

To crusher	minus 8 inches
To rolls	minus 1 1/4 inches
To Marathon mill	minus 1/2 inch
To Marcy mill	minus 4 mesh
To flotation	80 percent minus 200 mesh
To plates	3 percent plus 20 mesh 33 percent minus 35 mesh 100 percent minus 10 mesh (Tyler Standard)
Trommel oversize	6.8 percent plus 4 mesh

TABLE 3. - Operating data at the Atlanta mill for April 1934

Days operated	30
Men employed per 24 hours	20
Tons treated per man-shift	10.94
Ball consumption, pounds of steel per ton of ore:	
Marathon mill	1.65
Marcy mill	1.828
Total	3.478
Reagent consumption, pounds per ton of ore:	
Aerofloat	0.067
Potassium xanthate	.074
Cresylic acid	.084
Pine oil	.017
Barrett no. 4	.13
Soda ash	2.00
Mercury	.006
Copper sulphate	.60

TABLE 4. - Operating costs at the Atlanta mill for April 1934

(Tons treated, 5,904)

	Labor	Supplies	Power	Total
Crushing	$0.071	$0.011	$0.02	$0.102
Fine grinding	.089	.221	.18	.49
Amalgamation	.037	.045	.....	.082
Flotation	.072	.142	.048	.262
Filtering	.06	.002	.007	.069
Tailing disposal	.056	.001	.....	.057
Miscellaneous	.049	.....	.009	.058
Superintendence	.042	.....	.....	.042
Total	0.476	0.422	0.264	1.162

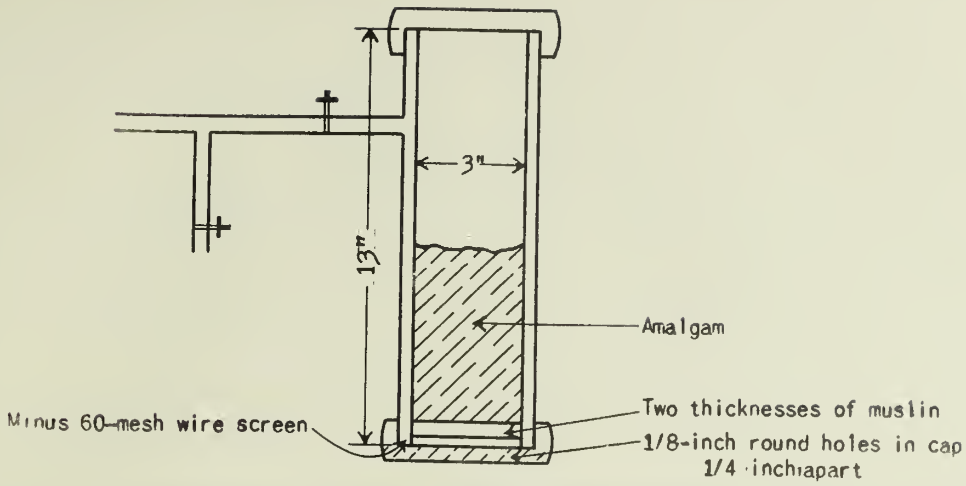

Figure 3.- Compressed-air amalgam press.

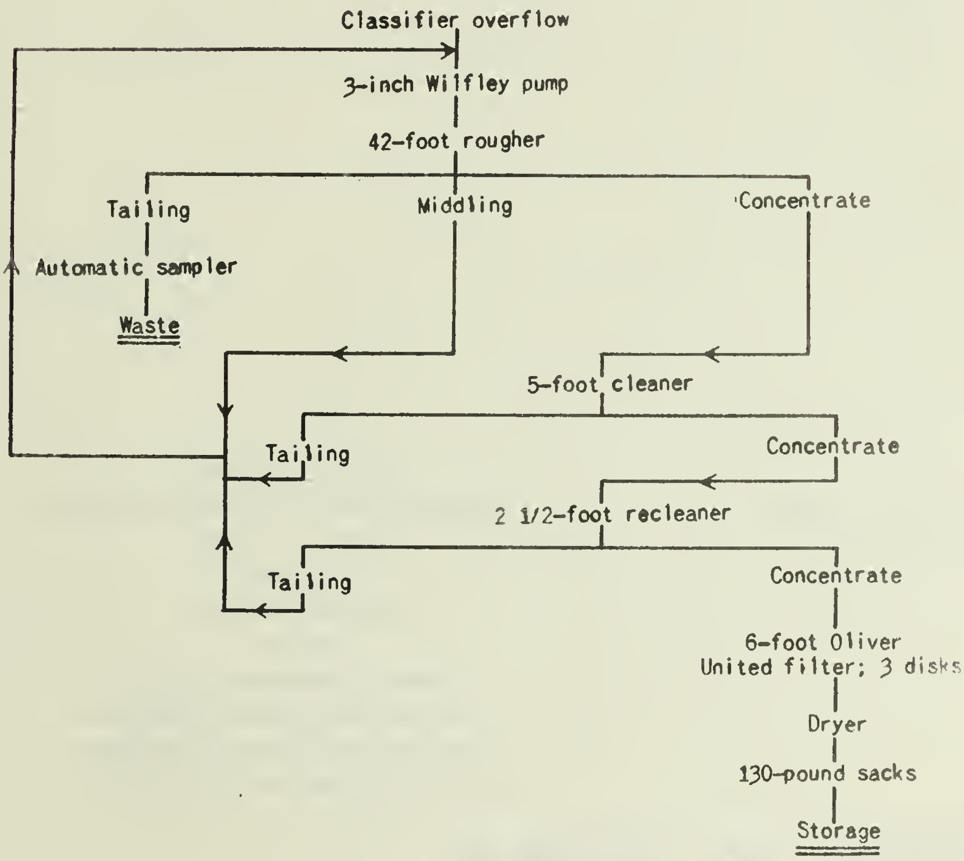

Figure 4.- Flow sheet of flotation circuit.

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

BLASTING PRACTICES AND EXPLOSIVES ACCIDENTS IN UTAH COAL MINES[1]

By D. J. Parker[2]

CONTENTS

INTRODUCTION

The ease of ignition and violence of explosion of Utah coal dusts, together with the large volumes of methane given off in some of the mines of the State, made it imperative to abandon obsolete equipment and obviously hazardous practices for up-to-date equipment and safer methods of mining if reasonable progress were to be attained in fire and explosion prevention.

Although much can still be done to improve safety conditions in Utah coal mines, considerable progress has been made in the past 10 years.

The fundamentals of such progress include increased use of permissible electrical equipment in gassy mines, closed lights, rock-dusting, more liberal use of water at the face, better ventilation, permissible explosives fired electrically both within and without the mine, partial inhibition of blasting while the shift is in the mine, 100-percent first-aid training, increased supervision and inspection, and mass safety meetings.

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6837."

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Virtually all small or "wagon" mines, chiefly those with relatively shallow workings of the so-called nongassy type, still cling to open lights and black blasting powder.

Many other coal mines of the United States also use black blasting powder and open lights notwithstanding the numerous hazards incident to their use and contrary to the teachings and recommendations of the United States Bureau of Mines and of others who have the real well-being of the coal miners of the United States at heart. As with rock-dusting, lighting, and other meritorious safety measures and equipment, the coal-mining industry as a whole has been slow to adopt safer and more economical methods of blasting.

The use of black blasting powder in Utah coal mines is limited, and its use for blasting in any mine is absolutely inexcusable, whether in Utah mines or those of any other State in the Union, and must of necessity invite disaster.

Between 5 and 6 percent of all fatalities in coal mines of the United States have been caused directly by explosives; at times Utah has been a far too generous contributor to this record, responsibility for which no one is willing to assume.

On May 1, 1900, 200 or more men were killed in Utah's greatest coal-mine disaster, following an explosion initiated either by blasting while the shift was in the mine or by the ignition of a quantity of black blasting powder by an open light. Again, in 1930 six fatalities in Utah coal mines resulted directly from explosives; the details of explosives accidents will be discussed later.

ACKNOWLEDGMENT

The author acknowledges gratefully his indebtedness to the Industrial Commission of Utah, the Utah Coal Operators Association, and individual operators for information used in the preparation of this manuscript.

BLASTING METHODS

The introduction into Utah coal mines of permissible explosives, fired electrically, has been one of the most progressive steps toward increased safety, and the industry is to be commended therefor. It is believed that no coal-producing State equals and certainly none surpasses Utah in safety in blasting practices.

Electrical blasting has been in effect in some Utah coal mines for more than 40 years and in all of the larger Utah coal mines since 1924; comparatively few accidents have resulted from the use of explosives in these mines.

Before July 1, 1924, some Utah coal mines blasted whenever occasion demanded, while the entire shift was underground, the miners firing their own shots at any time during the shift. For many years several coal mines have fired all shots electrically from the surface while all persons, including shot firers, were out of the mine.

As the result of a conference of company officials, the Utah Industrial Commission, and representatives of the United States Bureau of Mines the following rule was adopted in 1924:

> In all coal mines in Utah in which 3 or more men are employed on any 1 shift, all shots shall be fired electrically by authorized shotfirers when all men, except the shotfirers, are out of the mine.

This rule, as well as that requiring the use of permissible explosives in permissible quantities which was formulated at the same time, is now part of the State regulations with the force of State law, but in 1932 a ruling was issued authorizing blasting by Cardox during the working shift and in 1934 was confirmed after a public hearing by the Industrial Commission.

Since 1924 two principal methods of electrical blasting have been employed - firing all shots simultaneously from the surface with all men, including shot firers, out of the mine and firing one or more shots at a time by means of a battery or blasting machine with shot firers underground. The advantages and disadvantages of these two methods have been discussed widely; the apparent tendency in late years is to favor the latter method, with the shot firers underground, largely for reasons of economy in connection with mechanized mining though obviously more hazardous.

The data presented here compare the two methods of blasting, emphasize the safer and more economical one, and at least by inference call attention to the hazards of the less safe one.

The practice of allowing miners to blast at any time during the shift, with 3 or more men underground, is illegal at present, except when blasting with Cardox, and is unquestionably more hazardous and probably in the long run more expensive than either of the 2 methods of blasting now employed by most of Utah's larger mines.

SURFACE FIRING

The method of firing electrically from the surface by means of a master switch is essentially as follows: Firing lines are installed from the source of power on the surface to within a short distance of the working face and, as a rule, the conductors are well-insulated; further protection is afforded by several switches, including the gap-switch section or entry switches and place switches.

One type of gap switch consists of pieces of heavy wire or copper bars, approximately 6 feet long and preferably of unequal length, installed in the main firing circuit inside the mine but comparatively near the surface; this serves as an additional precaution to prevent power from entering the mine accidentally through the firing circuit, and the wide gap is a safeguard against high-voltage current - lightning, for instance - which might jump the gap of an ordinary switch.

Another type of gap switch in use is made by soldering sockets with flattened ends on the ends of the two main conductors. The gap is closed by inserting the flattened ends of the sockets into their respective contacts, to which are connected the outby sections of the main circuit leading to the master switch. When not in use the free ends of the 2 wires are disengaged from the contacts, bent backward, and locked in place, thus making a 5- or 6-foot gap in the main firing circuit. This switch is likewise underground but comparatively near the surface.

A third type of gap switch, used exclusively at one mine, is in the form of a gate made up of 1-inch pipe. The gate is supported by a 3-inch-piece timber set, and the wiring extends from 2 insulated contacts on the unhinged side of the gate through horizontal members of the gate to an intervening double-pole knife switch and thence to the master switch. When the gate is closed the contacts engage the terminals of the main underground firing circuit. When not in use the gate is locked in the open position. It is located in the manway about 50 feet from the surface; in addition to serving as a gap in the main blasting circuit, when closed it prevents access to the mine through the manway before blasting.

The section switch, which controls shooting lines of one or more panels or entire entries, makespossible the isolation of any section of district of the mine and also acts as an additional safeguard against stray currents.

The room switch is in the entry near or possibly just inside the room neck. Lines of relatively small-diameter insulated wire are strung from this switch to the face for the day's blasting; no. 10 wire is used on entries and no. 14 wire in rooms.

All wires and switches should be installed properly on insulators, and the supports holding them preferably should not carry any other source of electric current; some mines, however, make use of ordinary power lines, with relative safety, by properly installed switches and the enforcement of strict regulations concerning their use.

Shot firers load and tamp the holes, connect the wires, close the several switches (at least three separate switches), and at the end of the shift, blast by means of a master firing switch on the surface after all men, including themselves, are out of the mine. When the mine is reentered to inspect the shots the switches are opened in the reverse order, and all switches except room or place switches are locked securely.

If the permissible limit for explosives has not been exceeded, if the proper precautions have been observed in the installation and maintenance of the system, and if reasonable care has been exercised in loading, tamping, and placing holes the possibility of the occurrence of a fire or an explosion is remote; there certainly is no likelihood of injury to a workman and no chance of any extended disaster with heavy loss of life where the above system is installed and used carefully.

In blasting from the surface in the coal mines of Utah two types of master switches are used - the ordinary double-pole knife switch and a time-limit switch of the solenoid type. The latter type comprises three switches. The main switch is of the 2-pole type; before closing it, a plunger operating in a slotted 1-inch pipe is raised to the top of the slot and connected to the solenoid switch, which automatically releases the plunger when the 2-pole switch is closed. The plunger drops 6 feet 8 inches and opens a single-pole switch, thereby breaking the main circuit in case the 2-pole switch is still closed; it is therefore impossible to maintain the current on the firing circuit for a longer period than that required for the plunger to fall - 0.645 second or 645 milliseconds, without taking friction into consideration. The current therefore remains on the firing circuit during this time.

The question, on which there is little authentic information, has often been raised concerning the minimum time required for an electric current to remain on the blasting circuit and yet fire the shots. The Bureau of Mines recently tested a number of shot-firing units equipped with a special interior timing device which would allow the current to flow for approximately 5 milliseconds (0.005 second). Five timing tests made on each of 10 different machines showed a variation in the average timing of each machine of 4.31 to 6.60 milliseconds, although the timing for any individual machine was rather close to the average. These machines were designed to fire a maximum of 10 electric blasting caps in series. Two trials were made with one of the machines, which had a timing of 4.31 milliseconds. Five electric blasting caps were used in series in each trial, with 60 ohms added resistance; there were no misfires. A particular electric blasting cap, arbitrarily designated as G, was used in these tests. The electric blasting cap which fired 22 milliseconds after the current was applied was the first of the 10 to fire in the 2 trials. However, it should be remembered that there were 60 ohms added resistance, while in many shots fired within the mine the resistance is very much less.

Other tests indicated that with a very low line-resistance these G electric blasting caps would fire somewhat sooner - in about 7 milliseconds. This combination of a shot-firing unit, which cuts the current off the line in about 5 milliseconds, and of the G blasting caps, which under the most severe conditions - that is, with minimum resistance in the line - will not fire until about 7 milliseconds have elapsed, is very desirable because the voltage is off the shot-firing lines before the shot fires; therefore, no contact of the cap wires, the connecting wires, or the shot-firing cable can result from the blast at the face while there is voltage on the line.

Several types of electric blasting caps have been tested by the Bureau of Mines. None of them except the G has a lag exceeding 5 milliseconds, and few even approach it; that is, they all function much faster than the G.

These data cannot be readily translated directly into firing a large number of shots simultaneously outside the mine, but they indicate definitely that electric blasting caps can receive enough energy in an exceedingly brief time with a very moderate current - certainly much less than 1.5 amperes. This information should be valuable in a thorough study on the reduction of

the time of application of the firing current as now used in the coal mines of Utah. The time-limit shot-firing switch mentioned previously permits the current to remain on the firing circuit for 645 milliseconds. With the ordinary-type 2-pole master switch the current is applied to the firing circuit for approximately the same length of time, depending somewhat on the agility of the operator. These tests indicate that if enough energy can be given to an electric blasting cap in 5 milliseconds (0.005 of a second) the same principle can be applied to blasting from the surface in Utah coal mines.

The author realized that there is considerable difference between firing in series, as in the foregoing tests, and firing in parallel; when blasting caps are fired in series the same current passes through each bridge of each electric blasting cap, and when fired in parallel the current flowing through the different bridges may vary substantially. Most assuredly the current will vary substantially if the parallel circuits are unbalanced, as they would be normally, because there may be much more resistance in one circuit, which determines the amount of current passing through one bridge of a cap, than in another circuit, which determines the amount of current passing through another bridge, perhaps in another and more remote section of the mine. There remains the difficulty, however, of making and breaking contact with currents of much higher values than were used in these experiments. Alternating current at 180, 220, and 440 volts potential is now used in firing circuits when blasting is done from the surface.

UNDERGROUND FIRING

With shot-firers underground the shots are fired by a battery or blasting machine of the magnetic type, one or more holes being fired at one time. Several hazards attend this method of blasting, although it is much safer than any blasting method permitting the miner to blast as he desires.

GENERAL PRACTICES

Although far from perfect, practices in the storage, transportation, and use of explosives in Utah coal mines are for the most part commendable; from a safety point of view few States equal and none surpasses Utah. This is especially true of the larger producers.

In detailing some of the more important explosives practices common to the coal mines of Utah consideration is not given to the small or "wagon" mines, which produce only about 6 percent of the State's output.

As a rule, magazines are substantially constructed of masonry, maintained free of accumulations of debris, well-ventilated, and with no electric wiring. With few exceptions they are located in compliance with provisions of the American Table of Distances (1919 revision). Explosives are transported into the mine in well-constructed and thoroughly insulated boxes carried in insulated mine cars painted red and conspicuously marked and also brought in by the miners in canvas and rubberized fabric bags. Detonators are carried into the mine in special containers provided for that purpose by shot firers who usually walk into the mine. Wooden tamping bars and inert stemming (clay or

adobe) are used. The rules are that shot firers inspect the faces for the presence of methane before andafter blasting, and the face regions are wetted before blasting. In most mines the shot firers inspect the shot holes for depth, direction, and size before loading; such desirable inspection by trained shot firers is impossible where the miners load and tamp the holes. Preferably all shot holes should be inspected, loaded, tamped, stemmed to the collar, and wired as well as shot by shot firers.

In loading holes it is customary to place the first stick flush with the collar, shove this stick ahead with the second, and then place the third stick in the hole flush with the collar. The three sticks, including the primer, constituting less than the permissible limit of 1-1/2 pounds per charge, are then "pushed home" with the tamping bar. Pushing the entire charge home in one operation is fairly adequate insurance against possible gaps between the sticks of explosive due to drillings that may not have been removed from the hole; the chances of a partly exploded charge are thus reduced materially.

Primers are made by inserting the detonator full length into the side of the cartridge on an angle so that as far as is feasible the loaded end is about on the axial line and directed toward the bulk of the charge when placed in the shot hole. The detonator is secured to the cartridge by taking a half hitch around the latter with the leg wires. Shot firers of long experience claim that by this method there is much less likelihood of damaging the insulation of the leg wires by tamping than where the detonator is embedded in the end of the cartridge on the axial line. Furthermore, in side priming there is less danger that the detonator will pull out of the cartridge during the tamping than in end priming with the wrapper tied around the leg wires.

In the majority of Utah coal mines the three systems of wiring shots are series, parallel, and parallel-series, the two latter methods predominating. The method in use at any particular mine apparently is based on the results of considerable experience and perhaps to some extent on personal preference. Regardless of the method used, the desired results probably are attained if judged by the percentage of missed shots. Theoretically, straight series should be the most efficient method of wiring shots; however, the proponents of the other methods, especially the straight parallel, present some convincing evidence from a practical standpoint.

Missed shots ordinarily are handled by first attempting to fire each charge by a blasting machine, with no one underground except the shot firers. If the shot again fails to explode a parallel hole is drilled, generally under the personal supervision of the foreman, a safe distance from the missed hole and fired on the following shift. Meanwhile the detonator leg wires are disconnected from all wiring, "shorted" by twisting the ends together, and tucked into the collar of the missed hole. The location of a missed hole is identified by a suitable marker, usually a piece of white paper protruding from the collar.

If the charge in the parallel hole does not explode the charge in the missed hole, as is sometimes the case, it is decidedly hazardous to pick or

shovel into the loose coal, especially where mechanical loading is employed. However, diligent effort is made to locate the cartridges from the missed hole.

An instance is on record where an electric detonator was included in a domestic shipment of coal from a Utah mine to an adjoining State. When some of this coal was placed in a cookstove the detonator exploded, severely injuring one person; in consequence, the company making the shipment became the defendant in a heavy damage suit.

Another method of handling missed holes, employed to a very limited extent, is to wash the stemming out through a nonsparking pipe attached to a hose and then remove the charge. The primer and any cartridges outby may be pulled out by the detonator legs, and any remaining explosive can be removed with a wooden stick sharpened at one end. If the wrappers of the cartridges, other than the primer, are slit before loading, the charge may be washed out. After removal from the missed hole the explosive is taken to the surface and disposed of safely.

ANALYSIS OF EXPLOSIVES ACCIDENTS

Information has been obtained on all reported accidents (fatal and nonfatal) involving loss of time of more than 1 day due to explosives or their use or misuse for the 15 years 1919-33.

Data were available on 19 of the larger producing companies, which are representative of the State; for the most part, those not listed were small, intermittent producers.

Table 1 gives the tonnage produced during this period, or for those portions of the period during which the particular company operated, the number of fatal and nonfatal accidents caused by blasting or explosives, and the rates per million tons produced for fatal and nonfatal blasting or explosives accidents figured separately for each company. Data for the companies that now or formerly blasted from the surface with all men including the shot firers out of the mine and for those that blast with shot firers only underground are grouped in two periods - 1919-24 and 1925-33. The reason for the division into periods is that during 1924 blasting with the shift underground was prohibited and blasting from the surface was not introduced into some mines until about the latter part of 1924 or early in 1925. During 1924 electrical blasting was adopted by all companies shipping by rail, while the small or wagon mines apparently were exempted.

Some companies show a marked increase in the accident rates for the second period over those for the first, especially where they had no accidents in the first period and one in the second. Accidents attributable directly to explosives are so rare in the State that an attempt to tabulate the rates by years for individual companies, unless exceptionally large, gives a rather irregular result; however, when rates for the entire State for these two periods are compared a marked decrease is evident for the period during which all blasting was done with the shift out of the mine compared with the period when blasting was done in some mines with the working shift in the mines.

TABLE 1. - Fatality and injury rates per million tons caused by blasting or explosives

Company	Period of operation	Total coal production, tons		Fatalities		Deaths per 1,000,000 tons produced		Number injured		Injured per 1,000,000 tons produced	
		1919-24	1925-33	1919-24	1925-33	1919-24	1925-33	1919-24	1925-33	1919-24	1925-33
Blasting from surface											
Columbia Steel Corporation	1924-33	301,528	2,956,753	0	0	0	0	1	0	3.31	0
Liberty Fuel Co.	1919-33	995,906	1,581,136	0	0	0	0	2	0	2.01	0
Royal Coal Co. 1	1919-33	1,071,260	1,065,852	0	0	0	0	0	1	0	0.93
Spring Canyon Coal Co.	1919-33	2,287,258	3,509,595	1	0	0.44	0	3	3	1.31	.85
U. S. Fuel Co.	1919-33	6,135,321	6,445,880	0	2	0	0.31	9	2	1.47	.31
Utah Fuel Co. 1	1919-33	8,104,421	5,934,909	2	0	0.25	0	8	0	.99	0
Total and average		18,895,694	21,494,125	3	2	.15	.09	23	6	1.21	.27
Blasting from underground											
Blue Blaze Coal Co.	1926-33	0	1,399,645	0	3	0	2.14	0	2	0	1.42
Carbon Fuel Co.	1919-6/30/30	1,236,674	801,934	0	0	0	0	1	2	0.81	2.49
Chesterfield Coal Co.	1924-33	91,787	785,057	0	0	0	0	0	1	0	1.27
Grass Creek Fuel Co.	1919-6/30/29	156,011	73,297	0	0	0	0	0	0	0	0
Independent Coal & Coke Co.	1919-33	2,313,087	4,029,257	0	0	0	0	2	3	.86	.74
Kinney Coal Co.	1919-25	548,346	64,967	0	0	0	0	0	0	0	0
Lion Coal Co.	1919-33	1,078,344	795,392	0	0	0	0	0	1	0	1.25
MacLean Coal Co.	1925-33	0	141,533	0	0	0	0	0	0	0	0
Mutual Coal Co.	1922-33	513,445	1,037,921	0	0	0	0	4	0	7.79	0
Peerless Coal Co.	1919-33	935,290	961,686	0	0	0	0	0	1	0	1.03
Scofield Coal Co.	1919-33	467,754	412,724	0	0	0	0	5	0	10.69	0
Standard Coal Co.	1919-33	1,973,205	2,666,058	3	0	1.52	0	10	2	5.07	.75
Weber Coal Co.	1919-6/30/29	178,613	167,596	0	0	0	0	0	0	0	0
Total and average		9,492,556	13,337,067	3	3	.31	.22	22	12	2.31	.89

1 The Royal Coal Co. and the Utah Fuel Co. discontinued surface blasting on or about June 30, 1929, and January 1, 1929, respectively.

The death rate per 1,000,000 tons for the first group of companies (those blasting from the surface) for the period 1919-24 was 0.15 compared with 0.09 for 1925-33. Likewise the injury rates per 1,000,000 tons for the two periods were 1.21 and 0.27, respectively.

The fatality rates for the second group of companies (those blasting from underground) for the two periods were 0.31 and 0.22 and the injury rates 2.31 and 0.89, respectively.

Table 2 gives the accidents attributable directly to explosives, tabulated according to cause. These causes have been divided into 13 classes. The first 7 classes form a group of accidents that might happen regardless of the method of blasting; the last 6 are due directly to the method of blasting and are unlikely to occur if blasting is done from the surface.

Where surface blasting is employed the general practice in case of missed holes is to disconnect all wiring, mark the holes, and blast them from the surface on the succeeding shift. This procedure, however, is not always followed; in some instances shot firers fire missed holes with a blasting device before the shift enters the mine.

Regardless of the type of electrical blasting employed, there is always the possibility of a premature shot from stray currents, improperly made primers, or tamping the shot too vigorously.

When surface blasting was introduced in the different mines is not known definitely; accidents from unguarded or premature shots were possible early in the second period (1925-33) before this method of blasting was adopted.

The total number of accidents for 1919-24, before the adoption of electrical blasting and at a time when shooting during the working shift was common in some mines, was 51 compared with a total of 23 in 1925-33.

During 1925-33 the 6 companies blasting from the surface produced 61 percent of the tonnage and can be charged with only 34 percent of the accidents. Moreover, some of the accidents occurred in mines that blasted during the shift; the company operating these mines used surface blasting in most of its properties.

Six of the 12 fatalities during the 15 years 1919-33 occurred in 1930, which had by far the worst record for any year covered by this report.

Table 1 lists only 11 fatalities, although 1 fatality not recorded in the table occurred in 1930 in a wagon mine. Wagon mines produce approximately 6 percent of the State's tonnage, and with only the 1 fatality their explosives-accident record has been unexpectedly good.

Of the 6 fatalities in 1930 the first 2 resulted from the same accident. An entry was being driven through a rock fault several hundred feet in width; after a round of shots had been blasted the men were digging in the loose rock when some loose explosive was struck by a pick and detonated. In addition to

TABLE 2. - Classification of fatal and nonfatal explosives accidents

Company	Accidents from handling							Accidents from blasting							
	Transportation	Charging	Suffocation	Drilling into old holes	Striking into loose rock or coal	Thawing	Detonators	Unguarded shots	Returned too soon	Premature shot	Sparks from match lamp or candle	Delayed blast	Shot breaking through rib or pillar	Total	Grand total, 1919-33
1919-24															
Columbia Steel Corporation												1		1	
Liberty Fuel Co.												2		2	
Royal Coal Co.														0	
Spring Canyon Coal Co.									1		3			4	
U. S. Fuel Co.					1		3	2				1	2	9	
Utah Fuel Co.	1	1		2			1	2	1	1	1			10	
Blue Blaze Coal Co.														0	
Carbon Fuel Co.									1					1	
Chesterfield Coal Co.														0	
Grass Creek Fuel Co.														0	
Independent Coal & Coke Co.										1	1			2	
Kinney Coal Co.														0	
Lion Coal Co.														0	
MacLean Coal Co.														0	
Mutual Coal Co.								1	2			1		4	
Peerless Coal Co.														0	
Scofield Coal Co.									3			2		5	
Standard Coal Co.			1	1					6			1	4	13	
Weber Coal Co.														0	
Total	1	1	1	3	1		4	5	14	2	5	8	6	51	

TABLE 2. - Classification of fatal and nonfatal explosives accidents--Continued

Company	Accidents from handling							Accidents from blasting							
	Transportation	Charging	Suffocation	Drilling into old holes	Striking into loose rock or coal	Thawing	Detonators	Unguarded shots	Returned too soon	Premature shot	Sparks from match lamp or candle	Delayed blast	Shot breaking through rib or pillar	Total	Grand total, 1919-33
1925-33															
Columbia Steel Corporation 1														0	1
Liberty Fuel Co. 1														0	2
Royal Coal Co. 1								1						1	1
Spring Canyon Coal Co. 1		1		1						1				3	7
U. S. Fuel Co. 1		1			3									4	13
Utah Fuel Co. 1														0	10
Blue Blaze Coal Co.				5										5	5
Carbon Fuel Co.				1				1						2	3
Chesterfield Coal Co.	1													1	1
Grass Creek Fuel Co.														0	0
Independent Coal & Coke Co.				2		1								3	5
Kinney Coal Co.														0	0
Lion Coal Co.				1										1	1
MacLean Coal Co.														0	0
Mutual Coal Co.														0	4
Peerless Coal Co.									1					1	1
Scofield Coal Co.														0	5
Standard Coal Co.								1	1					2	15
Weber Coal Co.														0	0
Total	1	2		10	3	1		3	2	1				23	
Grand total	2	3	1	13	4	1	4	8	16	3	5	8	6	74	74

1 Companies that now or formerly employed surface blasting in some or all of their mines.

the 2 killed, 1 man was injured severely but recovered. One of the shot holes was cut off by the initial blast before the explosive was detonated, and part of the undetonated explosive became mixed with the "muck"; $1\frac{1}{2}$ sticks of explosive were found in the hole.

The second accident, which resulted in 3 deaths and 1 injury, occurred during the sinking of a rock slope. A missed hole containing 16 sticks of 60-percent straight dynamite, the presence of which was apparently unknown, was left in the bottom from a previous shift. The unbroken rock formed an obstruction to the proper extension of the track. It was then decided to drill and blast the projecting rock. Accordingly, a hole was started directly above and at right angles to the missed hole; the explosion followed when the drill struck the missed charge.

The third accident, which resulted in the death of 1 man, occurred in a small wagon mine under lease. The victim of the accident had drilled a shot hole near the top of the coal bed, which was 10 feet thick, and had charged it with 2 pounds of black blasting powder. Squibs were used to ignite the charge. Because of the height of the shot hole above the floor the deceased supposedly fastened a carbide lamp to the handle of a blasting needle and was attempting to light the squib at the tip end. Presumably the flame of the carbide lamp came in contact with the body of the squib, perhaps an inch from the end, and fired the charge before the victim had an opportunity to seek refuge from the blast.

It is interesting to note that of these 6 fatalities 5 occurred while driving through rock, which might indicate that the coal miner is less adept in such work than the more experienced metal miner. Such explosives accidents show the necessity for keen mental alertness, effective supervision, and rigid observance of the State mining laws if they are to be prevented.

SUGGESTIONS FOR REDUCING EXPLOSIVES ACCIDENTS

A few outstanding suggestions are offered to prevent explosives accidents:

1. Maintain blasting schools for educating the supervisory force, including foremen, fire bosses, and shot firers.

2. Buy explosives in such quantities that they can be used while still fresh.

3. Store explosives in a cool, dry place and in a separate magazine from detonators.

4. Use only extra-low-freezing permissible explosives which require no thawing.

5. Investigate thoroughly and report all accidents involving explosives or methods of firing.

6. Electrically short-circuit the leg wires of electric detonators by twisting or otherwise and maintain the short circuit until ready to connect to the shot-firing cable.

7. Electrically short-circuit the battery end of the shot-firing cable by twisting or otherwise and maintain the short circuit until ready to connect to the source of the electric current.

8. Test the shot-firing cable before connecting it to the electric detonator to make sure that no current is on the cable.

9. Use locked safety switches on all permanent shot-firing lines.

10. Disconnect the source of electric current from the shot-firing cable immediately after firing a blast and immediately after a misfire.

11. As a precaution against misfires maintain the permanent and temporary firing lines in first-class condition by using a high-quality insulated wire and inspect frequently.

12. Tamp all holes to the collar with incombustible material free of sharp or angular pieces.

13. As a precaution against premature explosions do not tamp explosives, primers, and stemming very vigorously.

14. Use only wooden tamping bars; they should not be shod with or have handles of metal.

15. The location of magazines should be governed strictly by the American Table of Distances (1919 revision).

CONCLUSIONS

Companies instituting methods of blasting from the surface and following them carefully and conscientiously have had noticeably low accident rates. Unquestionably at one time one or more gassy mines employing this method tended to load the shot holes beyond the limit of permissible explosives and also failed to consider depth and location of shot holes. With proper supervision and rigid discipline such obviously unsafe practices can and should be eliminated.

From an economic viewpoint some of the factors determining the advisability of surface blasting are thickness of bed, amount of methane given off, and efficiency of supervisory force. A bed of such thickness that two or more lines of shot holes are required across a face has the essence of dependent shots in all above the lower line. If the mine is gassy delay-action detonators cannot be used, and an extra brattice crew is required to replace the line canvas at the faces where all shots are fired simultaneously. If the bed is thick and the mine is classed as nongassy delay-action detonators sometimes are used in the upper lines of shot holes, line canvas, of course, not being necessary.

Where human life is involved, and unquestionably life should be the first consideration, the safest known method of using explosives to bring down coal is to blast from the surface while all men are out of the mine. A further reduction in explosives accidents could be expected if surface blasting were adopted more generally.

Although the progress of safety usually can be measured by the yardstick of costly experience much credit is due the coal industry of Utah for the adoption of the safest known blasting practices for coal mining, and any tendency toward a return to the obsolete and hazardous practice of blasting with the shift underground would be a regrettable and grave mistake, one likely to result in heavy loss not only of life but of property as well.

I.C. 6838
April 1935.

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

A FEW OF THE OPPORTUNITIES FOR OBTAINING ACCIDENT-PREVENTION INFORMATION AVAILABLE TO MINE MANAGEMENT AND EMPLOYEES THROUGH THE UNITED STATES BUREAU OF MINES[1]

An Accident-Prevention Program

By C. A. Herbert[2]

INTRODUCTION

The accident-prevention program outlined in this paper is based on the premise that most mine accidents are preventable, and in nearly all cases they are due to careless and dangerous practices and conditions that, as a rule, detract from efficient operation of the mine and may well be eliminated. That this is not a mistaken premise has been amply proved at mines where accidents have been reduced materially, if not to the minimum.

No claim is made that this is the only satisfactory program or plan for reducing accidents; the claim is made, however, that it is a workable program and if properly and intelligently adopted in part or in entirety will give satisfactory results.

THE PROGRAM

1. A Study of Accident Records and Reports

Obviously, if accidents are to be prevented the cause and type of accident must be known in order that intelligent steps may be taken to prevent their recurrence. Therefore, preliminary to beginning a safety program in which the Bureau's assistance has been requested, a Bureau engineer first studies the accident records and reports, usually tabulating the accidents according to cause and occupation if this is not already being done by the operator. A study of these reports and tabulations shows how and where most of the accidents occur. The completeness of this picture depends on the type of report required by the company. Unfortunately the accident reports and records of many (probably of most) companies are very meager insofar as

1 The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6838."

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concerns details of the actual cause of the accident. The cause of the injury (fall of rock, run over by cars, etc.) is given, but little or nothing is said regarding the contributing factors leading to the accident - absolutely necessary information if adequate, well-directed steps are to be taken to prevent similar accidents in the future.

2. Safety Inspection

After the accident reports have been reviewed and a more or less complete picture of the type of accidents and the classification of the labor experiencing the majority of the accidents has been obtained a safety inspection is made of the mine to gain first-hand information on operating conditions and practices. A study of the accident reports assists the Bureau engineer in making the inspection, as it gives him an idea of the hazards to be expected. The safety inspection includes numerous - one might almost say innumerable - features, among them a check on ventilation by taking air measurements and mine-air samples and a study of the coal-dust explosion hazard including the taking of dust samples.

A copy of the report of this inspection calling attention to any unsafe conditions or practices and making recommendations for their correction is sent to the operator if he desires this service.

3. Accident-Prevention Course for Officials

After completion of the mine inspection a series of meetings is held with the mine officials, usually once each week, and the cause and means of preventing the various types of mine accidents, such as those from falls of roof and coal, haulage accidents, and accidents from explosives and electricity are discussed. The average mine official is concerned primarily with getting the maximum production possible per man and machine and as a rule gives relatively little personal thought to the question of safety, although the coal company may have instituted some sort of safety organization or even may have employed a safety man. The various facts brought out in this series of meetings emphasize the responsibility of the mine officials as regards accidents and usually reveal many dangerous conditions and practices that have been permitted, practically all of which are not necessary to obtain maximum production at the least cost.

Changes in practice that will promote greater safety are generally pointed out, and many of them are put into effect as the meetings proceed; as a rule, the accident record is noticeably improved by the time the course is finished. In substance, a set of much safer operating rules or standards covering the various phases of mine operation is developed, and many of these, if not all, are put into practice by the officials.

Any safety program is necessarily educational. Men must be educated and trained to do their work in a safe way, which after all is the best and most efficient way, and the mine officials in daily contact with the men must assume the responsibility for their education and training. However, before they can hope to sell the idea of safety to the men under their charge they must first have an adequate conception of the idea themselves.

4. First-Aid Training

The Bureau of Mines has been training men in first aid for more than 20 years. At first this training was given solely by Bureau instructors to a limited number of employees at each mine. Later a new plan of first-aid training was inaugurated, by which a greater number of employees would receive the benefits of this training and a few capable not only of giving service in first aid but also of giving training in it would always be available at any mining plant. This plan provides enough additional training to certain selected employees to enable them to act as instructors under the supervision or guidance of Bureau of Mines instructors; it has operated very satisfactorily and makes possible the training of all the employees of even a large mine in a comparatively short time. Most of the Bureau's first-aid training throughout the United States is now given under this plan, and the result has been extremely gratifying. Where all or nearly all persons rather than a selected few at a mine or mining plant have taken first-aid training not only is qualified first-aid help virtually always present whenever an accident occurs but also those trained are usually safety conscious and take much greater precaution to avoid injury to themselves and to protect their fellow employees.

In addition, first-aid training not only teaches the men what to do in electric shock, arterial bleeding, or other severe injury, but it also plays an important part in any safety program. It makes each feel that he personally is taking an active part in the program; while taking the training he absorbs accident-prevention ideas and speculates on the needless occurrence of accidents as well as on available means of avoiding them. At the same time it puts him in a receptive frame of mind, making it much easier for the mine official to impress him with the thought that new safety rules that may be put into effect are for his own welfare or that of his fellow employees and should be obeyed.

First-aid training may be carried on at the same time or following the accident-prevention course to the officials.

5. Holmes Safety Chapters

To be successful any safety program must have the continued support and cooperation of the employees. It is believed that in most instances their support can best be won by the establishment and maintenance of a safety organization for employees which may meet monthly to discuss the accidents that have occurred during the month and suggest ways of preventing such accidents in the future. Entertainment of some sort or speakers may be provided for each meeting; at nearly every mine there usually is good musical or other talent that can be utilized. To encourage attendance, many operators furnish prizes such as safety shoes, safety hats, or clothing, which are drawn by lot or otherwise distributed.

Meetings of this type, at which the men and officials meet in a friendly and cooperative spirit, have done much to improve contract relations between the company and the local miners' organization.

A chapter of the Holmes Safety Assoc. offers a workable set-up for such a safety organization. This association is sponsored by the United States Bureau of Mines and in some regions has the endorsement of the United Mine Workers of America. At present there are about 400 chapters of this organization in the mining fields of the United States with a membership of approximately 70,000.

These are but a few of the numerous activities of the United States Bureau of Mines available to the mining industry in its effort to aid in the reduction of the numerous hazards that confront those who work in mines. The Bureau has done and is doing many other types of work to aid in bringing about safety in mining. There is no question that mines need to be operated much more safely than they have been in the past and that with the right type of safety program they can be operated with reasonable freedom from injuries to workers.

Some Questions and Answers on Safety Effort in Mining

In a discussion with a mine operator in regard to starting a safety program at his operations certain questions usually arise; some of these are given here, together with a suitable reply.

Question: What will this safety program cost our company?

Answer: Very little money but much time, hard work, and hard thinking on the part of every official connected with the company. The results obtained will be essentially in direct proportion to the amount of sustained, intelligent effort expended; if a mine organization is not altogether convinced that such a program is worth while or if it is mentally or physically lazy it probably would be better not to attempt such a program, as the results undoubtedly would be disappointing.

Question: Will the men support such a program?

Answer: Yes, if the mining company's officials are in earnest and show the employees that they are sincere and are not inclined to "pass the buck" to the men; safety in mining requires cooperative effort, with no holding back by either employer or employee.

Question: Has a similar safety program been tried anywhere, and what has been the result?

Answer: Many operating companies in the various mining States have put this or a similar program into effect either in part or in entirety, and almost invariably the results have been satisfactory. No attempt will be made to give detailed results obtained by these many companies, but instead one company (Knox Consolidated Coal Co., Bicknell, Ind.) near the writer's headquarters will be cited as an example. This particular company was chosen because, prior to beginning its safety campaign, it had a very unfavorable safety record; the results obtained are therefore much more striking than if it

had had a fairly good record at the beginning. Moreover, this company put the entire program as outlined in this paper into effect.

In spite of the fact that for years the mines of the Knox Consolidated Coal Co. were recognized as examples of well-operated and well-managed mines, their accident rates were decidedly unfavorable, particularly during 1932. Because of the 1932 record and the record for the early part of 1933 the management took decisive steps to improve accident rates. The results of its efforts are clearly depicted in figures 1 and 2.

The accident-frequency rate at No. 1 mine was reduced from 187.3 for 1932 to an average of 43.6 for the 15-month period July 1, 1933, to September 30, 1934; the accident-severity rate for this mine was reduced from 41.1 for 1932 and 62.6 for the first half of 1933 to an average of 1.3 for the same 15-month period.

At No. 2 mine the frequency rate was reduced from 137.7 for 1932 to an average of 30.9 for the 15-month period July 1, 1933, to September 30, 1934; the severity rate at this mine was reduced from 26.0 for 1932 to an average of 1.7 for the same 15-month period.

The accident-frequency rate is the number of lost-time accidents per million man-hours of exposure.

The accident-severity rate is the number of days lost as a result of accidents per thousand man-hours of exposure.

A lost-time accident is one in which the injured person is unable to report for work on the day following the injury.

In computing the severity rate a fatality or permanent total disability was given the standard valuation of 6,000 days, whereas in all other lost-time accidents the full number of days of disability was assessed against the mine, irrespective of the number of days the mine may have worked during the disability period.

The reduction in severity rates at these two mines is a good indication of the reduction in compensation costs; it is doubtful whether the equivalent amount of effort on the part of the officials toward reduction of operating costs in these or other well-operated mines or in any other phase of mine operation could have equaled the savings effected through their safety work. In addition, there is the great satisfaction of having prevented loss of life and crippling of workmen.

One of the interesting phases of the safety campaign of this company is the use of a "Thermometer of Accidents" on which is shown monthly the individual records of the bosses or foremen. Figure 3 is a sketch of this "thermometer" board. This maintains a spirit of rivalry which stimulates efforts to hold accidents to the minimum. The company also has a flagpole at both of its mines, and the mine having the lowest accident rate for the month is privileged to fly the flag during the succeeding month.

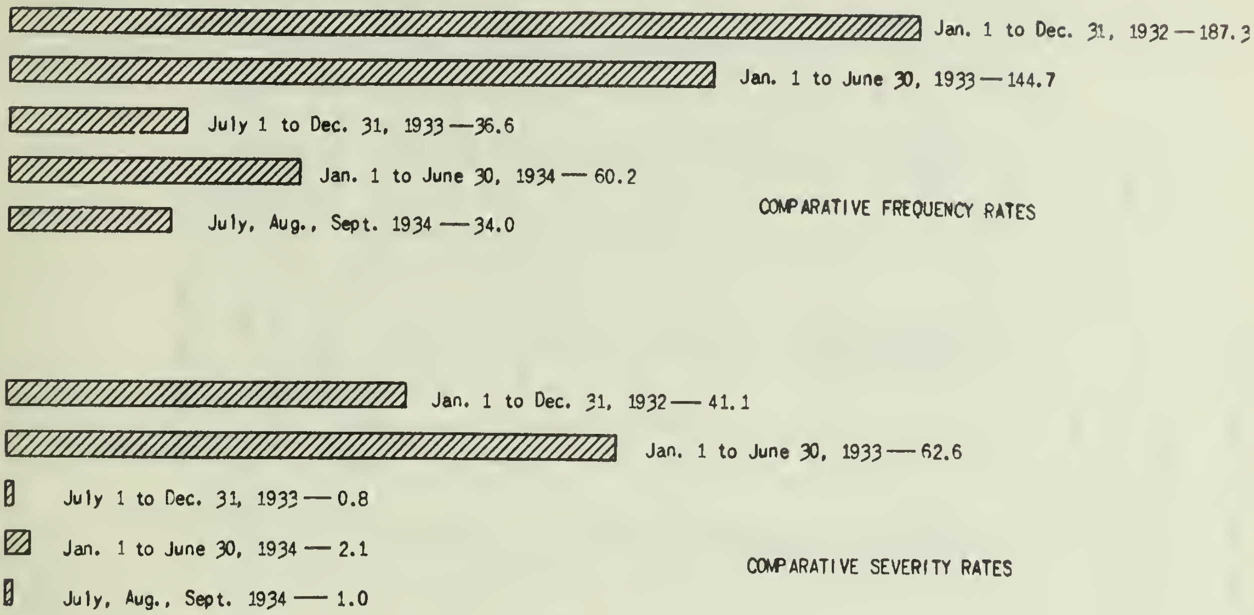

Figure 1.- Frequency and severity rates, Knox Consolidated Coal Co., No. 1 mine, Bicknell, Ind.

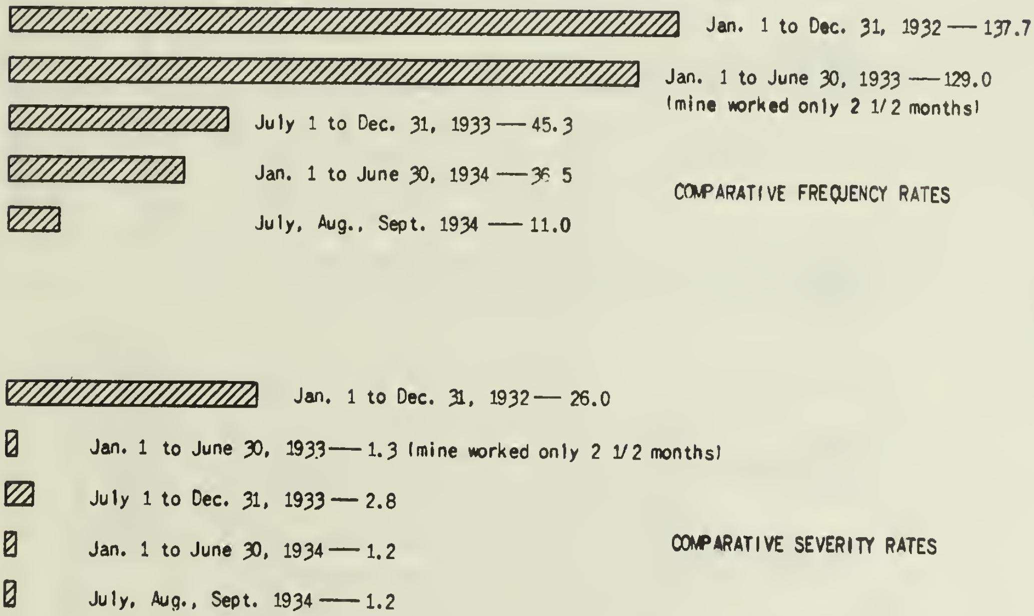

Figure 2.- Frequency and severity rates, Knox Consolidated Coal Co., No. 2 mine, Bicknell, Ind.

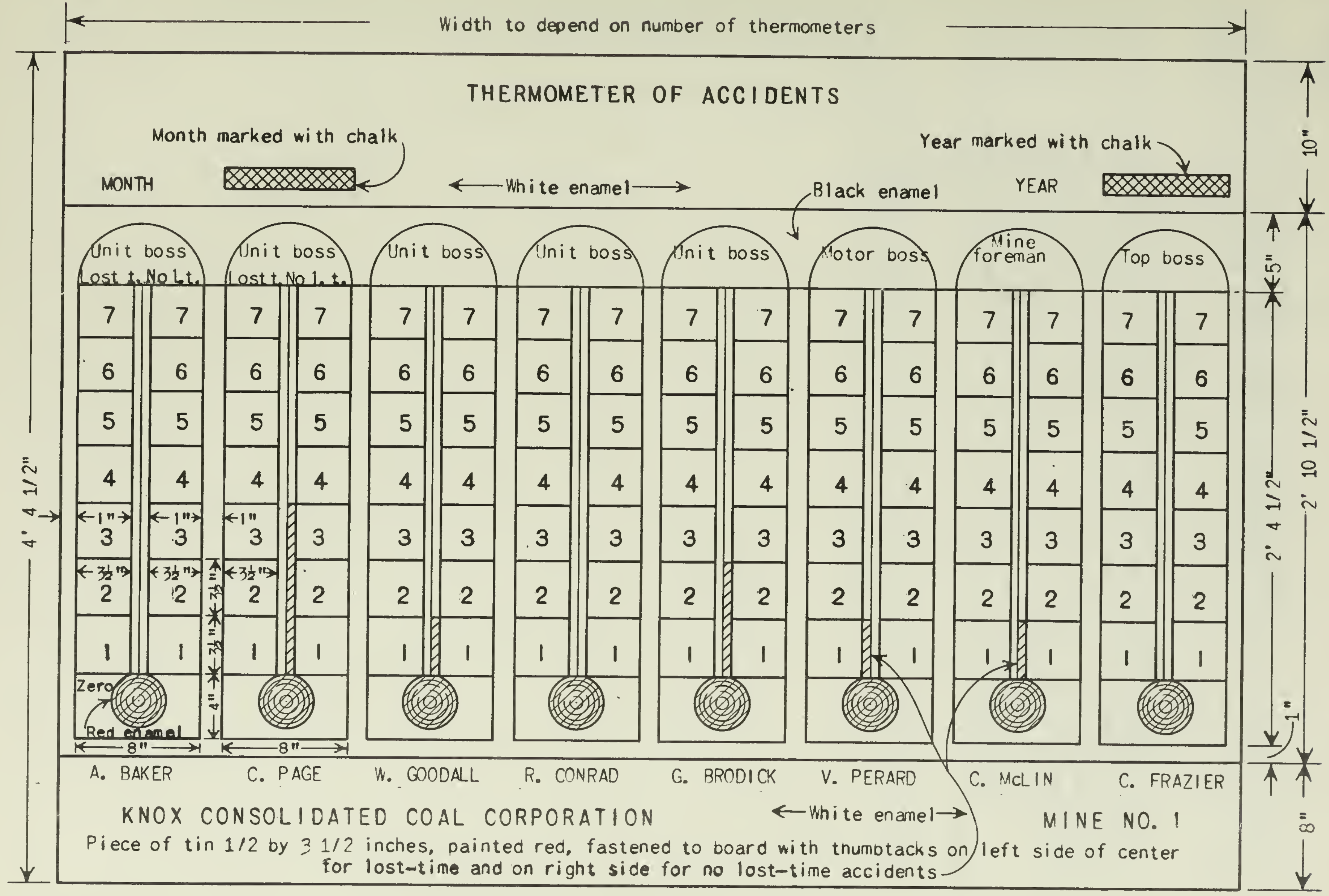

Figure 3.- Thermometer board, No. 1 mine, Knox Consolidated Coal Corporation.

The following is quoted from the closing paragraphs of a paper entitled "Can Coal-Mine Accidents Be Prevented" delivered by F. G. Conrad, superintendent of the Knox Consolidated Coal Co., before the Indiana Coal Mining Institute in June 1934:

> Since this campaign our mines are in better physical condition than ever before in our mining experience. We find that what we have done, in making our mines a safer place to work for our employees, has not increased our cost a fraction of a cent per ton. On the contrary, we have found that it lowers the cost, due to increased efficiency and better cooperation of our employees, to say nothing of the greatest saving of all - that of human life and limb. As a result of our efforts and the cooperation of our employees we have reduced the accident-frequency and severity rates at our mines more than 75 percent.
>
> I am sure that anything that we have done, you can also do. From the results and experience of this campaign, I can say without hesitancy, accidents in coal mines can be prevented.

I. C. 6839 May 1935

Department of the Interior

UNITED STATES BUREAU OF MINES
John W. Finch, Director

INFORMATION CIRCULAR

ESSENTIALS IN DEVELOPING AND FINANCING A PROSPECT INTO A MINE

BY

Charles Will Wright

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

ESSENTIALS IN DEVELOPING AND FINANCING A PROSPECT INTO A MINE[1]

By Charles Will Wright[2]

FOREWORD

This paper will be of interest to those who are actually developing a mineral prospect or planning to do so, as well as to investors who are considering the problem of financing the development of the prospect, so that they may know what the risks are and what capital expenditures are necessary before a prospect may become a mine.

The term "prospect" used broadly, as it is in this paper, is defined as any property that has a mineral showing of sufficient interest to warrant development, irrespective of prior work. Such previous exploration, however, may be extensive and consist of several tunnels or adits connected by raises, or of shafts with several levels. There may also be a small mining and milling plant on the prospect which, because of the lack of capital for development or the lack of markets for the products, is now idle. Such prospects may warrant further capital investment for development work or for a mine plant to raise to the stage of profitable production.

The four essentials that go into the making of a mine are:

(1) A prospect with a persistent or continuous ore body favorable for the development of a sufficient tonnage of profitable ore and located within a reasonable distance from water supply and transportation facilities.
(2) Sufficient capital for development work and for the installation and operation of a mine and mill plant to make the property remunerative.
(3) A ready market for the product.
(4) Competent and efficient management.

All four are necessary for success, but the last is particularly important.

To develop a mine, it must first be financed through the prospect stage. The risk of capital investment is greatest during this stage, and failures often may be ascribed to the unwise use of the available capital rather than to lack of minable ore and to mining conditions. The advice and opinion of a competent mining engineer are essential in any mining venture but are of major importance in the development of a prospect. The chances of failure are reduced greatly by the application of sound financing on business principles and by placing a man in charge of the work who has had technical training and experience in mine management. The death rate among promising prospects is very high. Some engineers claim that less than 1 percent of all prospects develop into profitable mines. All prospects, however, do not remain dead, and due to the stimulus of higher metal prices or improvements in metallurgical processes often are revived; sometimes these eventually become mines.

Before starting to raise capital it is necessary to have a detailed report on the property prepared by a competent mining engineer. Unfortunately, this is done in exceptional

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2 Chief engineer, Mining Division, U.S. Bureau of Mines.

cases only. Such a report should contain topographic and geologic maps, plans, and sections of the mine workings; assay records of the ore exposures, stating how samples were taken; and estimates of the tonnage and grade of ore developed[3], the possible tonnage that may be developed by future exploration, and the cost of such development work. Information Circular 6748, Essentials for a Preliminary Report on a Small Lode-Gold Mine or Prospect, with Notes on Sampling, written by the author, was issued in October 1933. Its object was to aid the owner of a small gold mine or prospect in preparing a report on his property for the purpose of interesting capital, but its essential features apply equally to ores other than gold.

Owners of small mines or prospects should prepare several copies of such a report, with illustrations and maps bound together. Fortified with information based on the data in such a report, they may then solicit financial aid. The investors, however, must know how much capital expenditure is required and justified and for what purposes it is to be used; and they also should have an estimate of the probable returns on the investment and when these may be expected. To make such an estimate is not an easy task, even for an experienced engineer, because there are so many unknown factors that have to be evaluated.

The object of this paper is to give to investors and mine owners a clearer conception of the risks they will encounter in attempting to make a mine out of a prospect and to point out the importance of geological studies, development work, tonnage estimates, mill tests, and management, as well as the market outlet and value of the product. Its purpose is also to point out to owners of a prospect the investors' viewpoint and ways to minimize risks to both owners and investors. Specific financing plans, providing enough capital to prepare the property for remunerative production over a period of years, are also improtant for its ultimate success.

In mining, as well as in other commercial enterprises, failure to anticipate capital requirements fully before productive operations are begun frequently has resulted in financial disaster to the enterprise. Thorough investigation and estimates of the ultimate cost of developing and equipping a property to the productive stage are therefore important before any major expenditure is started.

IMPORTANCE OF GEOLOGICAL STUDIES

Geological studies are necessary for determining the probable extent of an ore deposit, and one should have a clear conception of ore-forming processes before he makes estimates of ore reserves[4], particularly as to the tonnage of probable[5] and possible[6] ore present. It is only when these natural processes are understood that assumptions may be made as to the continuity and uniformity of mineral content. From a miner's standpoint ore bodies may be grouped in four general classes:

(1) Vein or lode deposits, where the ore minerals occupy a fissure or series of fissures in the country rock.

(2) Massive sulphide or replacement deposits, where the ore occurs in segregated masses, usually in limestone or in the vicinity of intrusive rocks.

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3 Ore developed or blocked out is that accessible for measurement and sampling on at least 3 sides not over 150 feet apart in regular deposits. In irregular deposits the estimate is based more on an engineer's judgment than on mathematical calculations.

4 Ore reserves are the estimated tonnage of ore to be mined.

5 Probable ore includes those portions of the ore body that have been exposed on two sides, plus a small portion of the ore body beyond these sides.

6 Possible ore includes areas within an ore body exposed on one side where ore may be reasonably expected to occur.

(3) Disseminated deposits, consisting of sulphide minerals scattered through masses of either intrusive or sedimentary rock .

(4) Bedded deposits.

Where prospects are in known mining districts a study of the neighboring mines should be made to obtain all available knowledge of the habits and occurrence of minable ore[7] in the vicinity, the size, shape, and persistence in depth of the ore shoots, and the possibility of faults and their effect on continuity of the ore.

The country rock in which the ore deposit occurs and the type of deposit as well, are important factors in determining the persistence of the ore body. Deposits in limestone and along contacts of intrusive rocks[8] with limestone and other sedimentary rocks usually are irregular in shape, and the individual ore masses often are limited in extent but sometimes are very large. Inferences drawn from outcrops as to the form and size of such contact metamorphic deposits[9] are unreliable, and predictions of extension much beyond exposed faces are unsafe. Exploration of such deposits should be confined to the borders of the intrusive rocks, except where a pronounced mineral zone extends outward from the intrusive masses.

Careful study of the occurrence of ore shoots[10] within a mineral zone or a vein or lode is also important in planning developments. Ore shoots may be distinguished by the presence of certain minerals or their relationship to geological features. Some occur where cross-fractures intersect a mineral zone or vein, others where the vein itself is strongly fractured or where there are vugs or cavities in the vein. Anticlines or synclines[11] in sedimentary rocks[12] are often favorable points for deposition of ore, and the proximity of dikes may also be indicative.

Most nonferrous metalliferous deposits occur in districts of abundant igneous[13] intrusive rock , and the ore bodies often are found close to the contacts of the intrusive masses. In certain areas it has been observed that fingerlike extensions from large masses of intrusive rocks point to the places where the ore bodies occur. In other instances they occur where the intruded rocks form embayments in the line of contact.

The proximity of an ore body where limestone is the enclosing rock sometimes is indicated by dolomitization[14] of the limestone, a change that may extend a considerable distance from the ore body. Where shales or schists enclose the ore bodies there is often a silicification[15] of the wall rocks, and the rock near the ore bodies is of a lighter color or appears to have been bleached.

A trained geologist will observe numerous chemical and structural characteristics. From these observations, together with a carefully prepared geological map of the area where the ore bodies occur, interpretations may be made which are of utmost importance in planning

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7 Minable ore is ore which will yield a profit under normal conditions.

8 Intrusive rocks are those rock masses or dikes that have been pushed up into the bedded rock, such as granite and porphyry.

9 Contact metamorphic deposits are those that occur in the altered rock areas between the intrusive rock masses and bedded rocks.

10 Ore shoots are portions of a vein or ore body carrying high-grade or paying ore.

11 An anticline is an arch or fold of rock strata bulging upward, while a syncline is a U-shaped fold.

12 Sedimentary rocks are composed of material derived from the erosion or decay of other rocks.

13 Igneous rocks are those consolidated from a molten state; they include both volcanic and intrusive rocks.

14 Dolomitization is the change from limestone to dolomite caused by an impregnation of carbonate of magnesium into the limestone, forming a calcium magnesium carbonate.

15 Silicification is caused by the penetration of solutions carrying silica and depositing this silica in the rocks adjacent to the fissures in which ore may occur.

the future development of an ore body. The new edition of Ore Deposits, by W. Lindgren,[16] presents clearly the value of geological studies, and The Principle of Economic Geology, by W. H. Emmons,[17] gives an excellent discussion of all kinds and types of ore bodies and their formation.

Certain types of ore deposits are more continuous than others. The vein and lode deposits are the most persistent, and predictions often can be made with some degree of certainty as to the continuity of ore between known points for deposits of this type. However, it is seldom safe to gage the size of a treatment plant by information based on estimated tonnages of possible ore in ore bodies which have been exposed on one side only or opened by a single tunnel or drift.[18]

Often the metal content of an ore deposit depends upon whether it has been subjected to secondary enrichment.[19] In northern glaciated regions primary ores usually extend to the surface, and oxidation with secondary enrichment is unimportant. In dry climates, where erosion has been less, time has allowed extensive decomposition of the ore bodies near the surface, and part of their metal content has been carried in solution and deposited at lower levels. As the extent of this secondary enrichment varies greatly with depth and as the metal content of the ore is not uniform, estimates of possible ore beyond known limits are highly speculative. It is therefore necessary to recognize secondary enrichment and to determine by exploration whether valuable ore may exist below the ore exposed and whether the enriched ore will be succeeded in depth by workable primary ore.[20]

Well-defined fissure veins that are exposed for a thousand feet or more along the surface would be expected to continue for several hundred feet in depth, under normal conditions, unless they are cut off by some structural feature in the enclosing rocks that is not apparent from the surface. Such structural terminations may be caused by a sudden pinching or closing of the fissure in which the vein occurs or by a fault displacing the ore body, beyond which its extension is uncertain.

Examples

(1) A deposit of copper ore in southeastern Alaska, which occurred on a mountain divide at the contact of a granite mass with limestone, was partly explored by trenches and short tunnels. Due to oxidation of the sulphide deposit, malachite, azurite, and limonite were formed, and these surface minerals were spread over a wide area, giving the appearance of a large deposit. Instead of sinking a shaft to determine the depth of the deposits a tunnel 2,000 feet long was driven to develop the deposit at a depth of 600 feet. Meanwhile an aerial ropeway, smelter, and wharf were built. No ore was disclosed by the tunnel, and later the deposit was bottomed by a shaft at less than a hundred feet below the surface. Had the shaft been sunk in the ore at the start or a tunnel driven 100 feet below the outcrop about a million dollars in useless expenditure would have been saved. Moreover, examination of the other copper deposits in this area would have shown that this type of ore body was limited in lateral and vertical extent and secondary enrichment confined to within a hundred feet of the surface.

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16 Lindgren, W., Ore Deposits, 4th ed.

17 Emmons, W. H., The Principles of Economic Geology: McGraw-Hill Book Co., New York, N.Y.

18 The term "tunnel" is used commonly instead of adit or drift, although if strictly interpreted a tunnel is an opening extending entirely through a hill, but in mining literature and among mining men a tunnel is a passageway into a hill.

19 Secondary enrichment of a vein or an ore body is an enrichment by material of later origin, usually derived from the oxidation of decomposed, overlying ore masses.

20 Primary ores are those first or originally formed in an ore deposit before alteration began.

(2) A vein deposit of lead ore in sericite schist had been developed and mined over a length of 3,000 feet above the adit level. A shaft was sunk 200 feet, and at a depth of 100 feet a level was opened up for a length of 1,000 feet; this showed the vein to be wider and just as rich as on the upper level. Estimates were made of probable and possible ore down to and below the 200-foot level, and based on these estimates a new mill and power plant were built. The 200-foot level was started in ore, but a pinch in the vein, which extended the entire length of the vein between the 100- and 200-foot levels, was encountered a short distance from the shaft. Winzes were sunk below the 100-foot level at several points until the pinch was found. Exploration below the 200-foot level failed to disclose the extension of the vein below the pinch. Based upon the assumptions made and upon normal conditions for this type of deposit the capital expenditure would have been recovered, but the example shows that speculations on estimates of possible ore are hazardous.

IMPORTANCE OF GEOPHYSICAL PROSPECTING METHODS

Geophysics has been a valuable aid in many instances in exploration of mineral deposits. Both electrical resistivity methods and the magnetometer have been used extensively in tracing the extension of ore veins and faults and in determining subterranean geological features that affect the occurrence of minerals. It is, however, no easy matter to interpret the results of the field survey , and to do so usually requires a thorough knowledge of geology. At most, these surveys can show only certain anomalies within an area that will correspond to those caused by an ore body, a fault, or some geological characteristic in a known area and thus indicate a favorable place for exploration. It is therefore most important to use more than one geophysical method within an area, so that the geophysicist may be prepared to check the interpretation of the data and to make detailed geological studies before he begins costly underground explorations. Geophysical methods also are used to check geological deductions and supplement them, and in any extensive mine development the use of these methods should be considered.

IMPORTANCE OF DEVELOPMENT WORK

Misguided and insufficient exploration of the ore bodies is often the reason for failure to make a mine out of a prospect or to make a mine a profitable producer over a period of years. Lack of capital frequently prevents owners or operators of small mines from extending development work unless they can do so out of profits from the ore. To make a salable product may require a milling plant, the expenditure for which, based on the ore exposed, may or may not be justifiable. However, the desire to produce, not only by the operator but by those who have financed the initial development work on the prospect, spurs them to put up more capital for unwarranted expenditures on plants in the hope of quick return rather than to use this capital for essential development work. No expenditure on a treatment plant is justifiable until a sufficient tonnage of ore is developed to return the capital expenditure out of profits from the ore reserves. There are also many cases of failure where the tonnage of ore developed is ample, but the owner has wasted his capital on machinery or equipment purchased without adequate knowledge of requirement .

The owner of a prospect should realize that an examining engineer is particularly interested in the tonnage of ore exposed and the prospective profits to be derived from this ore. He therefore should concentrate upon exposing and blocking out ore in the most promising portion of the deposit and should extend exploration to find the continuation of this deposit or additional deposits. An ore deposit may have merit, even though only a small tonnage is exposed. Although the owner may have faith in what future development will show

a competent examining engineer knows the risks of making assumptions, and rather than take such risks he will turn down the undeveloped prospect. Of the prospects examined by engineers it is estimated that only about 1 percent are reported upon favorably, the reason frequently being the lack of tonnage developed or unreasonable price or terms rather than low assay values.

Methods of Development

The topography of the surface and the type of the ore deposit are usually the deciding factors in planning the development of a mineral prospect.

To determine the most advantageous way to develop an ore body one should have good topographic maps of the surface, and on this the trenches, tunnels, drifts, and shafts along the ore deposits should be indicated. Where underground development work has been extensive a plan and vertical sections of the workings are essential guides in planning further work. The position of the ore body, as well as faults, dikes, and other geologic features, should be indicated on these mine plans and sections.

Surface Explorations

Surface exploration of any ore deposit should be carried on as extensively as possible, because this is usually the cheapest way to get information. A vein or other type of ore body should be located by cross-trenching at intervals and then exposed by stripping along its strike, if possible. Where the overburden is not too deep for such work a series of trenches usually is dug at regular intervals, at right angles to the strike. The distance between trenches is determined by the type of ore body and the depth of the soil; trenches should be close enough to determine the average width of the ore body and to avoid missing ore shoots and to permit proper sampling of the ore. Trenches over ore shoots are spaced more closely than over barren areas. Where good ore is found test pits are made to permit sampling well below the surface. Usually a vein or ore body will show in a general way the same variations in size and values along the surface as will occur in depth, although there are many exceptions.

Underground development in flat areas requires vertical or inclined shafts, from which drifts are extended along the vein or ore body, while in mountainous areas development often is carried on by a series of tunnels at different levels. The size and number of the shafts or tunnels will depend upon the daily tonnage to be extracted. Where large tonnages are to be mined provision should be made for underground storage bins and loading pockets.

Tunnels, Drifts, and Crosscuts

In a mountainous country it usually is possible to open up a vein or ore body by a drift or tunnel along the vein or by a crosscut to intersect the vein or ore body and then by drifts to develop it along its strike. The advantages of developing an ore deposit from a tunnel or adit compared to shaft-sinking are obvious. A tunnel is the cheapest method; as the workings are self-drained, no machinery is required for hoisting, haulage costs are lower than those for hoisting over the same distance, and the cost of tunneling or drifting is usually about one third that for sinking a shaft.

Shafts

Veins or other types of deposits coming to the surface may be developed by: (1) Inclined shafts following the ore body as nearly as possible along its dip either in the ore

body or in the footwall, (2) vertical shafts adjacent to the ore body with crosscuts to the deposit, (3) a combination of vertical and inclined shafts or of a tunnel and a shaft.

The advantages of an inclined shaft are that it is kept in or close to the ore, thus avoiding crosscuts and permitting development of the vein by drifts in the ore in two directions, while the ore taken out may pay part of the development expense.

The advantages of the vertical shaft are: (1) Hoisting is faster, there is less wear on the hoisting rope, safety devices may be applied more efficiently, no pillars of ore are required for protection, except in passing through veins or deposits, and water can be bailed or pumped out more easily.

Shaft sinking is the most costly form of development work, but in some instances is the only type possible. In the development of vein deposits inclined shafts are sunk, usually following the vein or in the footwall of the vein, and are to be recommended for new developments. The inconvenience of hoisting in an inclined shaft usually is not serious enough to justify sinking a vertical shaft in country rock. The cost of a prospect shaft ranges from $7 to $60 per foot, depending on size, depth, and rock. Numerous examples, with detailed costs and speed of sinking, are given in Bulletin 357, Shaft-Sinking Practices and Costs, by E. D. Gardner and J. F. Johnson; Information Circular 6800, Mining and Milling Practices at Small Gold Mines, by E. D. Gardner and C. H. Johnson; Bulletin 381, Lead and Zinc Mining and Milling in the United States, Current Practices and Costs, Chas. F. Jackson, John B. Knaebel, and C. A. Wright; and Bulletin 363, Gold Mining and Milling in the United States and Canada, by C. F. Jackson and J. B. Knaebel.

Mine Levels

Whatever the method of entry into an ore body, mine levels or drifts, as well as crosscuts, are necessary to develop the vein or ore deposit laterally. Starting from the shaft the intervals between these mine levels usually range from 100 to 200 feet. The question of the economic interval between mine levels is discussed at length in Information Circular 6613, Factors Governing the Selection of the Proper Level Interval in Underground Mines, by William O. Vanderburg.

Drifts are extended at these level intervals along the ore body, which is prepared for stoping by raises and chutes. These raises are spaced according to the shape of the deposit to permit the extraction of the ore with the least amount of handling as well as purpose of ventilation. The cost of drifting and crosscutting varies from $2 to $20 a foot, the average cost being about $6.00. For raises the cost per foot may be slightly less. Direct cost of hand-drilling is about the same as with power drills, except in very hard rock. The progress, however, with an equal number of men working is only about one third as fast as with power drills.

Attention given to the position of a development drift in ore with reference to the walls of the vein or ore deposit will be of value when ore above the drift is stoped. If the vein is quite steep, the drift may be run equally well with the vein on either side, or in the middle. If the vein dips 60 degrees or less it is more convenient to have the drift in such a position that the stope floor will intersect the side of the drift high enough to install chutes for loading a car or a bucket.[21]

Usually there is no difference in the size or shape of drifts and crosscuts. Crosscuts in general require less timber than drifts, because the country rock away from the ore zone usually is less fractured and altered and is therefore stronger.

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21 Jackson, Chas. F., and Knaebel, J. B., Underground Chute Gates in Metal Mines: Inf. Circ. 6495, Bureau of Mines, 1931, 22 pp.

Numerous examples and detailed costs of drifting and crosscutting are given in the series of papers on mining methods and costs during the last few years by the Bureau of Mines and in the Mining Engineers' Handbook, by Robert Peele.

Sampling and Exploration by Means of Hammer Drills

For underground sampling and exploration of ore deposits, light hammer drills, using unjointed bars of steel, are used widely as a means of determining the presence or the width of ore bodies 5 to 20 feet beyond the existing faces. The cuttings from such holes are collected and assayed, and the grade of the ore is calculated on the basis of the assays from these drill-hole samples. Fairly reliable results thus may be obtained at a low cost, and often parallel veins or lenses of ore have thus been discovered which otherwise would have been missed. Deep-hole drilling with heavy hammer-type machines and sectional steel frequently is used for holes up to 500 feet that are horizontal or inclined up to a 30-degree angle. The sludge is collected for the sample. In southeast Missouri, using a heavy Leyner-type machine, holes 35 to 78 feet were drilled at a contract labor cost of 16 cents per foot, according to Knaebel.[22] It is generally assumed that the "deep-hole" method is less expensive than diamond drilling, but for holes over 100 feet long the cost per foot with the new light diamond-drill outfits is not much greater than drilling deep holes. One has the advantage of speed and a core of the country rock as well as the ore which for purposes of correlation are better than sludge samples.

Diamond Drilling

The object of diamond drilling is to outline known ore bodies and to prospect outlying areas, to block out ore reserves and guide mine developments. The diamond-drill core is a representative sample of the ore and rock traversed and may be assayed to determine the metal content of the ore and studied to determine the geological relations of the rock.

Diamond-drill cores range in diameter from 1 inch to 2 inches, according to the depth of the hole, and the machines are operated by compressed air, gasoline, electric or steam power. The water required is 60 to 110 gallons per hour, of which there is about 25 percent loss, if all water returns to the collar of the drill hole and the overflow from the sludge box can be reused. A consumption of 60 to 70 barrels a day is an average for deep-drilling outfits. The drilling speed ranges from 1 foot to 8 feet an hour actual drilling time, which is 25 to 50 percent of the total time. The cost of drilling is $2.00 to $6.00 a foot, with some records below $2.00 and many instances where the costs were over $6.00.

As diamond drilling requires specialists to obtain the best results the work usually is done on contract, except at large mines with trained crews for the work.[23 24]

Shot Drilling

Shot drills, which use steel shot in place of diamonds in core drilling, are used extensively in sampling bedded deposits from the surface. The advantages of the shot over the diamond drill are its ability to bore holes of large diameter and the low cost of the abrasives of the bit; moreover, less experience is required of operators. The average speed for a 3-1/8- to 5-inch core in average rock is 1 foot per hour. Shot drilling is limited to

22 Knaebel, John B. Sampling and Exploration by Means of Hammer Drills: Inf. Circ. 6594 Bureau of Mines, 1932, 29 pp.
23 Peele, Robert, Mining Engineers Handbook: 2d ed., John Wiley & Sons (Inc.), New York, 1927, pp. 373-400.
24 Hansen, Mayor G., Diamond Drilling at the United Verde Mine, Inf. Circ. 6708, Bureau of Mines, 1933.

downward holes from 45 degrees to vertical. Shot drill holes may cost more per foot than diamond-drill holes due to the higher power consumption. For more specific data the reader is referred to the catalogue of the Calyx Shot Drill Co. and to pages 391 to 393 of the Mining Engineers' Handbook, by Robert Peele.

Churn Drilling

Where vertical holes from the surface are required these can be made with a churn drill. Such holes usually are 6 inches in diameter; when drilling is done in solid rock the speed is 1 to 2 feet an hour and the cost $0.50 to $6.00 per foot, with a probable average of about $2.50.[25]

SAMPLING AND TONNAGE ESTIMATION OF ORE DEPOSITS

The basis for any investment in a prospect are the average assay values of the ore and the tonnage of ore developed. The importance of getting and properly presenting such information often is not realized by the owner until he attempts to interest capital in developing his property. Bureau of Mines Bulletin 356, also Information Circular 6748, and the Mining Engineers Handbook describe in detail the standard methods of ore sampling and making tonnage estimates.[26]

The regular deposits in which the valuable minerals are distributed uniformly are the simplest type to sample by the ordinary drill or channel sampling methods and sampling becomes increasingly difficult with more erratic mineralization. In veins containing precious metals irregularly distributed there is the question of rejecting pieces of visable metal in the sample or discarding the exceptionally high sample assays in making up the averages. The size of sample to be cut and the sample interval are also important considerations and depend upon the distribution of the ore minerals in the gangue. The more uneven this distribution is, the larger the size of the sample and the smaller the interval between samples in order to obtain satisfactory results. The mineralization in some ore deposits is so erratic that only by a large tonnage mill test can the average grade of the ore be determined.

In making tonnage estimates certain assumptions have to be made regarding the continuity and grade of ore between exposed and sampled openings and extensions of ore beyond exposed ore faces. The accuracy of the estimates will depend to a large extent upon the experience, integrity and soundness of judgment of the engineer responsible for them.

Tonnage estimates are usually classified under three separate headings: "Developed ore", "Probable ore", and "Possible ore." Developed ore is usually ore, the continuity and grade of which have been proved on four, or at least three, sides not over 150 feet apart, and allowances should be made for loss in mining and dilution with waste. Probable ore includes the portions of the orebody that are exposed on two sides plus small additional portions beyond these sides, but here, too, the engineer must limit himself to certain conservative distances for extensions of ore beyond exposed faces. In estimating possible ore more latitude may be taken in deciding the limits of the ore occurrence beyond the known faces but these limits must be based on logical geological criteria or interpretation.

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25 Peele, Robert, Mining Engineers Handbook: 2d ed., John Wiley & Sons (Inc.), New York, 1927, pp. 356-366.

26 Jackson, Chas. F. and Knaebel, J. B., Sampling and Estimation of Ore Deposits: Bull. 356, Bureau of Mines, 1932 155 pp.

Wright, Charles Will, Essentials for a Preliminary Report on a Small Lode-Gold Mine or Prospect, with Notes on Sampling: Inf. Circ. 6748, Bureau of Mines, 1933, 12 pp.

Peele, Robert, Mining Engineers Handbook: 2d ed., John Wiley & Sons (Inc.), New York, 1927, pp. 1845-1964.

MINING METHODS AND COSTS

The features that influence the choice of mining methods are size, shape, and dip of the ore body, continuity in depth and length, regularity of ore boundaries, strength of ore and wall rocks, grade of ore and distribution of metal contents, structural irregularities, faults, slips, joints, and fracture zones. In the usual type of vein deposit where the wall rock as well as the ore is fairly solid the open stope or cut-and-fill methods are in most common use. If the walls are not strong enough, then stulls or square-sets are used, often followed by filling. All these methods permit sorting of ore in the stopes and selective mining. The shrinkage and caving and sublevel-stoping methods are applied to large, low-grade deposits for large-scale or wholesale mining.

Large production requires large ore bodies and large initial investment in development and preparations. Where such operations are contemplated the problems of safety, good ventilation, and continuity of flow of ore from the stopes to the cars, taking the utmost advantage of gravity, are of prime importance for low-cost operation.

Mining conditions being the same, a narrow (2- to 3-foot) vein will cost twice as much per ton to mine as a vein 6 to 8 feet wide, but if the vein is 10 to 20 feet wide the mining cost will be only slightly less than that of a 6-foot vein.

The advantages and disadvantages of the different mining methods and comparative results at a large number of mines in the consumption of man-hours, explosives, power, and supplies per ton mined, are given in Information Circular 6503,[27] by the author.

The following tables are taken from this paper:

Average results for different mining methods; 1929 figures

Mining method	Man-hours per ton, all underground labor	Tons per man-shift, all underground labor	Explosive used per ton, pounds	Power, kw. hr. per ton	Total underground cost per ton
Square-set..........	5.15	1.553	1.363	34.9	$4.825
Average of......	61 mines	61 mines	10 mines	19 mines	11 mines
Cut-and-fill......	4.34	1.843	.660	10.045	$3.076
Average of......	21 mines	21 mines	5 mines	4 mines	5 mines
Shrinkage...........	1.33	6.015	1.656	15.33	$2.682
Average of......	37 mines	37 mines	18 mines	16 mines	16 mines
Open-stope..........	1.17	6.837	.844	8.90	$1.250
Average of......	170 mines	170 mines	22 mines	17 mines	19 mines
Sublevel caving	.95	8.421	.605	13.00	$1.438
Average of......	17 mines	17 mines	4 mines	2 mines	2 mines
Top slicing........	.932	8.584	.520	7.252	$1.208
Average of......	37 mines	37 mines	13 mines	12 mines	3 mines
Caving...............	.628	12.739	.244	3.0	.516
Average of......	7 mines	7 mines	3 mines	3 mines	4 mines
		Surface			
Opencut...............	.324	24.691	.308	2.71	.309
Average of......	55 mines	55 mines	3 mines	3 mines	3 mines

27 Wright, Charles Will. Mining Methods and Costs at Metal Mines of the United States: Inf. Circ. 6503 Bureau of Mines, 1931, 39 pp.

The following table shows roughly the relative consumption of labor, explosives, and power, according to the metal mined; the number of mines from which the data were obtained is indicated in each case. With data from more mines and for a period of years, these averages would be more representative.

Labor, explosives, and power consumption in metal mines

Metal	Man-hours per ton mined	Man-hours per unit of product	Explosives, pound per ton mined	Power kw. hr. per ton
Iron underground	1.14 (94 mines)	2.35 (tons)(94 mines)	0.548 (30 mines)	8.38 (30 mines)
Iron opencut	.39 (48 mines)	.82 (tons)(48 mines)	....	....
Copper underground	1.63 (63 mines)	.046 (lb.)(63 mines)	.439 (10 mines)	7.64 (10 mines)
Copper opencut	.29 (7 mines)	.014 (lb.)(7 mines)	.308 (3 mines)	2.71 (3 mines)
Lead and zinc	2.01 (161 mines)	.022(lb.)(161 mines)	.920 (15 mines)	17.65 (15 mines)
Gold	1.27 (31 mines)	6.41 (oz.)(31 mines)	.844 (8 mines)	9.72 (8 mines)

UNDERGROUND MINING PROBLEMS

Underground problems include drilling and blasting practice, underground support, mechanical loading, mine transportation, ventilation, drainage, and safety. The following are some of the Bureau of Mines publications on these subjects that may interest mine operators.

Bull. 306 Crane, W. R., Mining Methods and Practice in the Michigan Copper Mines: 1929, 192 pp.

Bull. 311 Gardner, E. D., Drilling and Blasting in Metal-Mine Drifts and Crosscuts: 1929, 170 pp.

Bull. 330 McElroy, G. E., Ventilation of the Large Copper Mines of Arizona: 1930, 145 pp.

Manuscript Report 1 Jackson, Chas. F., Underground Scraping Practice in Metal Mines: 1934.

I.C. 6086 McElroy, G. E., Why, When, and How to Make a Ventilation Survey of Metal Mines: 1928, 12 pp.

I.C. 6326 Jackson, Chas. F., Some Notes on Underground Transportation: 1931, 40 pp.

I.C. 6382 McElroy, G. E., Mine Ventilation in the Coeur d'Alene District, Idaho: 1931, 37 pp.

I.C. 6495 Jackson, C. F. and Knaebel, J. B., Underground Chute Gates in Metal Mines: 1931, 22 pp.

I.C. 6501 Crane, W. R., Essential Factors Influencing Subsidence and Ground Movement: 1931, 14 pp.

I.C. 6651 Crane, W. R., Abstracts of Recent Articles on Mine Support: 1932, 23 pp.

Initial Mine Plants

The machinery required to do the development work will depend upon the development plan and capital available. Where capital is limited many ingenious, inexpensive devices are used to operate compressors, hoists, pumps, and haulage equipment. It is usually possible to buy second-hand machinery, such as oil- or gasoline-driven air compressors, rock drills, hoists, pumps, mine cars, and track and electrical dynamos and motors at about half the cost of new machinery. The question of transporting machinery to a prospect must also be considered, and the size and weight of individual pieces should conform to the available means of transport.

Foundations and housing are also to be added to the cost estimates for the plant, and good construction is important for the plant. Besides the housing for the mechanical equipment, quarters for workmen, a change house, boarding house, and warehouse, a carpenter and machine shop and assay office may be necessary as work progresses. The question of a year-round water supply for mining, milling, and domestic purposes is important.

In making estimates for the cost of a mine plant, one should refer to Peele's Handbook of Mining and to catalogs of manufacturers of mining machinery. The following papers, issued by the Bureau of Mines, on costs of equipping mines also contain specific information on individual operations as well as valuable suggestions for those contemplating new mine developments and plant installations:

(1) I.C. 6591 Reigart, John R., The Cost of Developing to the Operating Stage and Equipping a Small or Medium-Sized Mine in the Tri-State Lead and Zinc District: 1932, 18 pp.
(2) I.C. 6601 Sweet, J. R., Mining Methods and Costs at the Mt. Hope Mine of the Warren Foundry and Pipe Corporation, Mt. Hope, N.J.: 1932, 31 pp.
(3) I.C. 6674 Howes, G. A., and Jackson, Chas. F., Shaft-Sinking Methods and Costs, and Cost of Plant and Equipment at the Macassa Mine, Kirkland Lake, Ontario: 1932, 10 pp.
(4) I.C. 6681 Keast, A. J., and Jackson, Chas. F., Method and Cost of Exploring, Equipping for Development, and Developing the Central Patricia Group of Claims, Northern Ontario: 1933, 13 pp.
(5) I.C. 6693 Jackson, Chas. F., Some Notes on Methods and Costs of Equipping and Developing Prospects: 1933, 24 pp.
(6) I.C. 6707 Emens, W. H., and Jackson, Chas. F., Methods and Costs of Developing and Equipping the Ashley Gold Mine, Matachewan Gold District, Ontario: 1933, 28 pp.
(7) I.C. 6730 Sweeney, E. L., Design, Equipment, and Construction Costs of the Davis-Dunkirk Concentrator, Prescott, Ariz.: 1933, 5 pp.

IMPORTANCE OF MILL TESTS

The method of treatment for the ore must be known before a mine can be valued, as its net value depends upon the percentage of metal that can be recovered economically and the cost of recovery. Where concentrates are sold to a smelter not only will there be further metal losses, but deductions will be made for deleterious or undesirable elements, besides the smelting charges. It is important to know what these deductions and charges will be.

For properties that have been in operation, these factors are known, but for newly developed properties it usually is necessary to have a large-scale mill test preceded by laboratory tests to determine the method to be used for the large test. Such tests require 1 to 100 tons of average-grade ore and the cost at commercial testing plants will range from $500 to $5,000. If ore of similar character is being treated within the district the mill results from these plants should be obtained and their flow sheets studied.

Trouble has been experienced with many small properties due to faulty design and construction of milling plants based upon inadequate and inconclusive tests for determining the best flow sheet. In other instances, 100- to 200-ton mills have been erected where a 25-ton mill might have brought the prospect into production. The matter of getting the right advice is highly important, and the time one needs good advice is before starting to build a mill. The United States Bureau of Mines and the State mining bureaus and colleges are sources for information on methods of ore treatment. The textbook by Arthur F. Taggart, Ore Dressing, is another good source, and valuable information may be obtained in Robert Peele's Mining Engineers' Handbook.

COST OF MILLING PLANTS

The cost of a mill will vary according to the nature of the ore and the method of treatment required. A flotation or amalgamation mill will cost $500 to $800, multiplied by the number of tons the mill will treat in 24 hours. Where well-constructed buildings are necessary in northern districts the cost is higher than in southern districts, where lighter construction suffices. The total cost of mills for complex ores, where two or more methods of ore treatment are combined in one plant, and for an all-slime cyaniding plant will be $1,000 to $1,500 per ton capacity in 24 hours.

Just what treatment is required depends upon the character of the ore to be milled, and it is often necessary to work out a flow sheet for the treatment of an ore using a combination of methods to get a high recovery. As most mill plants undergo changes in their flow sheet or system of ore treatment it is better to begin with a pilot plant of 10 to 20 tons capacity per 24 hours rather than to erect a 100- to 200-ton mill. Such procedure will give more time to iron out difficulties in the milling problems and to develop the mine. It may be found that a mill of only 50 tons per day capacity is large enough instead of a previously contemplated plant for 200 tons. There are many failures on record where capital has been spent on large-capacity mills for small-capacity mines, whereas the mine might have been successful with a small mill. In some instances the reason for this is the urgent demand of the investors or shareholders for profits before the mine is ready for production on a profitable basis.

MILLING COSTS

Milling costs range from 25 cents to as high as $10 per ton, depending upon the capacity of the mill, the methods of treatment used, and the ability of the mine to keep the mill running at full capacity. Shut-downs due to lack of ore or to mechanical troubles all increase the costs, and these are more serious for a mill with large capital investment than for a small one. Overhead expenses, such as administration, amortization, taxes, insurance, and interest all run 24 hours a day, and the mill should do likewise.

Details of milling costs for the different methods of ore treatment and size of plants as well as the cost of plant construction are given in the handbooks referred to by Taggart and Peele; for individual operations reference is made to the following papers on small mill plants:

(1) I.C. 6430 Blackburn, W. H., Milling Methods and Costs at the Lead-Zinc Concentrator of the Treadwall Yukon Co., Ltd., at Tybo, Nev.: 1931, 14 pp.

(2) I.C. 6447 Vanderburg, Wm. O., Milling Methods at the Hughesville Concentrator of the St. Joseph Lead Co., Hughesville, Mont.: 1931, 15 pp.

(3) I.C. 6476 Woodworth, Selim E., Milling Methods and Costs at the Argonaut Mill, Jackson, Calif.: 1931, 12 pp.

(4) I.C. 6497 Andrus, D. E., Milling Methods and Costs at the Montana Mine Concentrator of the Eagle-Picher Lead Co., Ruby, Ariz.: 1931, 14 pp.

(5) I.C. 6508 Dixon, John, Milling Practice of the Kirkland Lake Gold Mines (Ltd.), Kirkland Lake, Ontario: 1931, 13 pp.

(6) I.C. 6541 Redington, John, Milling Methods and Costs of the Coniaurum Mines, (Ltd.), Schumacher, Ontario: 1931, 5 pp.

(7) I.C. 6730 Sweeney, E. L., Design, Equipment, and Construction Costs of the Davis-Dunkirk Concentrator, Prescott, Ariz.: 1933, 5 pp.

(8) I.C. 6739 Bean, J. J., Milling Methods at the Oxide Concentrator of the International Smelting Co., Tooele, Utah: 1934, 18 pp.

INVESTIGATION OF PLACER MINES

E. D. Gardner, in part I of Placer Mining in the Western United States (Inf. Circ. 6786) says:

> Failure to sample and estimate properly the available yardage of placer deposits has resulted in a tremendous waste of money and effort. A large proportion of all placer operations has failed because the gold in the gravel was insufficient to repay the cost of even the most efficient mining, not to mention the return of money invested or interest thereon.
>
> Many methods of sampling are available, including the simple panning of gravel from natural exposures, drifting, test-pitting or trenching, shaft-sinking, and churn-drilling. Actual mining on a small scale often is done as a method of sampling prior to investing considerable money in development or equipment.
>
> A gravel deposit of much size seldom can be sampled directly from its natural exposures; but a few creek banks, steep-sided gulches, or old excavations such as hydráulic pits may be available, in which case certain precautions should be taken to get true samples. First, the vertical extent of gravel to include in a given sample should be determined. If hydraulicking is to be done, the whole depth of gravel ordinarily is included in one sample, except when it is planned to pipe off the barren overburden to waste, in which event it is desirable to know the depth of barren material and samples may be taken of each distinguishable stratum. If drifting is planned, only the lower, economically minable gravel need be sampled. After the location and extent of a sample cut have been decided, care must be taken to have equal quantities of gravel from all points along its length. The best way to do this is to cut a channel or groove of uniform shape and size from top to bottom of the sample distance. Enough such samples must be taken to prove the continuity of the 'pay streak.'
>
> Shaft sinking is the usual method of testing placer ground. Prospect and sampling shafts, unless intended for later use in drifting or mining and unless exceptionally deep (75 feet or more), are sunk as small as practicable. The usual section is rectangular and in most districts is commonly used to crib shafts in loose gravel. In gravel tight enough to stand safely without lagging the only timber necessary is stulls set to hold the ladder.
>
> In river flats sub-surface waters usually prevent extending a shaft to bedrock, and in such instances drive-pipe sampling is the only solution.
>
> The sampling of placer deposits by drilling, or, more precisely, drive-pipe sampling, is discussed in detail by Janin.[28] He states that the Keystone no. 3 traction machine is used generally in California. The usual casing is 6 inches inside diameter and 3/8 inch thick, in 5- to 7-foot sections. Drilling without casing is not good practice, and high values in a hole so drilled cannot be accepted. The bit and stem weigh 800 to 1,000 pounds. The cutting shoe usually is about 7 1/2 inches in outside diameter. Theoretically this dimension is the diameter of the cylinder of material excavated, hence it determines the yardage per foot of hole drilled. A sand pump is used to lift the loosened gravel or sludge from the hole, usually after each foot of drilling when in pay dirt. The casing is driven ahead of the tools except when boulders or cemented gravel prevent . The casing is recovered after finishing the hole.

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28 Janin, Charles, Gold Dredging in the United States: Bull. 127, Bureau of Mines, 1918, pp. 30-49.

Regardless of the method used, the samples taken from each foot or several feet of drilling usually is treated in a rocker, and the concentrates are panned to recover the gold. The colors are classified by eye according to size, usually into three groups, and a record is made of the number of each. Generally the gold is then amalgamated with a small quantity of mercury, which at the completion of the hole is dissolved in nitric acid. The gold is then weighed to give the total yield of the hole. Frequently the tailings from rocking and panning are saved and reconcentrated at the completion of the hole to detect and recover gold lost during the first washing.

The value of gravel in cents per cubic yard equals weight of gold recovered in milligrams times value of gold in cents per milligram times the conversion factor 27 (cubic feet per cubic yard), divided by the depth drilled in feet times the cross-sectional area of the hole, or briefly,

$$\underline{V} \text{ (cents per yard)} = \frac{\text{weight of gold (mg)} \times 0.06 \times 27}{\text{depth drilled (feet)} \times 0.3068}.$$

As an aid in determining the depth of placer deposits, geophysical prospecting methods have been applied successfully in many instances. Where the bedrock is of homogeneous or uniform magnetic permeability and where considerable magnetite is associated with valuable gold concentrations, magnetometer surveys can outline these leads quite accurately.[29] The instruments used most for this purpose are the Thompson-Thalen, Askania and Hotchkiss magnetometers, which measure slight changes in the intensity of the earth's magnetic field. Operation of these instruments is not difficult, but correct interpretation of the results requires experience.

Where uniform bedrock conditions do not exist the magnetic work must be supplemented with electrical work to obtain complementary data for use in interpreting the magnetic anomalies. The electrical work gives information on thickness of gravel and depth to bedrock, contour and outline of the underlying bedrock, and other structural features which may be of value in planning the mining operations.

It must be emphasized that no geophysical method or combination of methods is offered by reputable engineers as a means for determining the commercial value of placer-gold deposits. However, information gained by geophysical methods as to the physical features of the deposit are of great value both in subsequent testing and in developing and operating the property.

Apart from the deposit itself, the water supply is the most important factor in determining the application of hydraulicking and the scale of operation. Under any given conditions the daily yardage is roughly proportional to the quantity of water used. The quantity excavated likewise is proportional to the head used on the giants, but the higher pressure is of less value in driving and washing and of none at all in sluicing the gravel through the boxes to the dump. As the cutting and sweeping capacity of the giants usually exceeds the carrying capacity of water a stream of flowing water, known as 'by-wash', or 'bank water', is directed through the pit and into the sluices.

The preparatory or development work necessary to start hydraulicking usually is greater than that for any other form of placer mining except dredging or drift

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29 Laylander, K. C., Magnetometric Surveying as an Aid in Exploring Placer Ground: Eng. and Min. Jour. vol. 121, Feb. 20, 1927, pp. 325-328.

mining. A deposit preferably is opened at the lower end to permit gravity drainage and progressive mining of the entire deposit in an orderly fashion.

A single mine may have many miles of ditch, costing perhaps $2,500 per mile, as well as dams and reservoirs and thousands of feet of flumes, tunnels, or inverted siphons. The mechanical equipment of a hydraulic mine ordinarily consists of a few hundred to a few thousand feet of 10- to 30-inch, or larger, iron pipe, one or more monitors, and a varying number of sluice boxes; the cost of equipment ordinarily is small compared to the expenditures necessary for ditches and tail races.

Although it is obvious that the recoverable gold content of the gravel must pay a profit over operating costs, which usually range from 5 to 20 cents per yard, a surprising number of ventures in hydraulicking have failed because the promoters have not allowed for all the preparatory expenses noted above. Each yard of gravel mined must carry its share of this cost, therefore the size of the deposit is of utmost importance in considering a hydraulic mining venture.

Hydraulicking under suitable conditions is a low-cost method as it yields a larger production per man-shift than any other method except dredging. The initial investment required is less than that for dredging; hence, hydraulicking in small or medium-size deposits may be more economical even though dredging would result in a lower operating cost. When the operations are on a very large scale hydraulicking costs are lower than dredging costs on a comparable basis Very clayey or bouldery gravels should be hydraulicked as dredging usually is unsatisfactory in such ground."

To determine the profits from placer deposits of known yardage and value is a simpler and, one might say, a safer undertaking than estimating profits from vein or lode deposits. Costs depend upon the method to be used, water supply, and yardage to be treated per shift. Costs as low as 4 cents per cubic yard are being obtained in dredging and hydraulic operations and as low as 10 cents in drag-line operations, but they are often many times higher.

It is of utmost importance that those intending to finance a placer property have it examined and sampled by a competent placer-mining engineer rather than base their estimates and plans of operation on reports prepared by the owner of the property. The increased interest in gold mining has attracted many operators experienced in sand and gravel operations who may have idle equipment and inventors with "trick" gold-saving machinery who wish to test their devices. These men, inexperienced in placer mining, fully believe that all that is necessary is to find a placer deposit and get capital to start operations. They induce their friends to help finance their ventures or promote a company for public subscription. Nearly all such attempts have been unsuccessful; they have failed principally because the yield from the placer deposit was less than was anticipated and the operating costs higher than estimated.

In any placer-mining undertaking it is advisable to use only standard equipment which has been proved to be the simplest and most satisfactory.

Gardner, in the information circulars mentioned, presents a number of tables giving cost data and other information on a number of placer mines classified according to the method of operation. The reader is also referred to the reports by the State mining bureaus and to the following publications:

Janin, Charles, Gold Dredging in the United States: Bull. 127, Bureau of Mines, 1918, 226 pp.

Wilson, E. B., Hydraulic and Placer Mining: John Wiley & Sons, New York, 1918.

Wimmler, Norman L., Placer-Mining Methods and Costs in Alaska: Bull. 259, Bureau of Mines, 1927, 236 pp.

Boericke, W. F., Prospecting and Operating Small Gold Placers: John Wiley & Sons, Inc., New York.
Gardner, E. D. and Johnson, C. H., Placer Mining in the Western States:
Part I - General Information on Shoveling and Ground Sluicing: Inf. Circ. 6786, 1934, 73 pp.
Part II - Hydraulicking, Treatment of Placer Concentrates and Marketing of Gold: Inf. Circ. 6787, 1934, 89 pp.
Part III - Dredging and Other Forms of Mechanical Handling of Gravel and Drift Mining: Inf. Circ. 6788, 1935, 81 pp.
von Bernewitz, M. W., Handbook for Prospectors: McGraw-Hill Publishing Co., Inc., New York.

IMPORTANCE OF MARKET STUDIES

As the gross profit from mining operations is the market or selling price of the product minus production and transportation costs one must consider with greatest care what the future average prices for the metal to be mined probably will be. Such an estimate not only takes into account past price averages but what future demands may be for the product under consideration and what the competitive mineral products are and their selling prices. One must also consider the other sources of supply of the product, the production costs at these sources, and their proximity to the markets.

Thus far there always has been a market for gold, and the prices of other metals are based on the relative value of gold. The last decade, however, has shown what variations may occur in metal prices, as well as in other mineral commodities. The following table shows some of these changes:

Average price, cents per pound (New York prices)

Metal	1911-20	1921-30	1931	1932	1933	1934
Copper	18.9	14.1	9.1	6.3	6.4	8.53
Lead....	5.8	6.5	3.7	3.0	3.9	3.86
Zinc....	8.4	6.3	3.8	3.0	4.0	4.51

The low prices during the last few years are no more the real prices of the metal than are the highest prices during the preceding years.

One may well ask what price should be taken for a metal or other mineral commodity in making estimates that may be regarded as safe. There are many publications that present the price curves for the metals, some going back for over 100 years, and by studying these price curves and taking into account what has been already mentioned a forecast of probable future prices may be made.

IMPORTANCE OF COMPETENT TECHNICAL ADVICE AND EFFICIENT MINE MANAGEMENT

During the past 2 years the Bureau has collected records of over 1,000 gold mines, old ones reopened and new ones developed by newly organized companies. A detailed study of the field notes indicates that only a small percentage of these operations by newly organized companies were successful, was due to three things: Insufficient tonnage of profitable ore, inexperienced or poor management, or inadequate financing. Quotations from Bureau of Mines engineers' field reports will illustrate this point.

W. O. Vanderburg, in a letter dated June 2, 1933, wrote as follows:

I believe that 95 percent of the small mines visited are being operated by men who were honest. This was contrary to what I expected to find, although it must be admitted that in many cases the operators are not getting the most for the money spent. One major criticism in the small-mine field is the building of mills before sufficient ore has been developed to justify their erection. The plan followed in many instances is to build the mill first and then start looking for ore. In some cases after the mill was built the operator had no funds available for development work. Another common fault in the small gold mine field was the lack of planning in underground development. Very few of the mines had maps of any sort of the underground workings.

In a letter dated June 10, 1934, E. D. Gardner stated:

It is surprising to see the number of old gold properties that have been opened up by men from other lines of business. One day last week, I visited six mines in one locality. One was being operated by a building contractor from Kansas, another by a manufacturer from Chicago, a third by an electric furnace man from Pittsburgh, and so on. The sixth was managed by a so-called engineer. I doubt his mining ability, however, as he had five surface men servicing two men in the hole. The electric furnace man was building a furnace to smelt his concentrates which he may or may not make.

It is beyond all understanding why people who have been successful in non-engineering lines feel so confident they can operate a gold mine successfully. In some cases, if the money holds out long enough they learn enough to get by. In others there is not enough money in the world for them to become educated in mining. In practically all small gold operations, management or supervision consists of two thirds finding the ore and one third getting it out.

If the prospective mine operator would engage a competent mining engineer to advise him at the start rather than after an unsuccessful attempt to develop a mine the number of failures would be less. The question of management cannot be overemphasized, as so much depends upon the judicious expenditure of each dollar. A manager should not be picked because he will accept the job for half the salary of a more experienced man, as new mines cannot afford to pay for the mistakes of the inexperienced. The ability of a manager to get the most out of the men under him is another important qualification.

A paper by the author on Management of Labor in Successful Metal-Mine Operations (Inf. Circ. 6650), which was published by the Bureau of Mines in August 1932, presents the problem encountered in the development of efficient mine organizations and shows the methods used by certain mining companies in promoting efficiency.

A mine manager must know human nature and use tact in dealing with personnel problems, both with the staff and with the workmen. He must have the ability to devise ways and means of reducing costs and must exert influence over the entire organization so that both staff and workmen will endeavor to promote the company's interest. Above all, he must be an engineer with years of mining experience and of unquestioned integrity.

Managers of small mines, like many operators of small industrial companies, do not always recognize the value of accurate accounting control over their operations. To meet this situation, Bulletin 372, Accounting System and Office-Management Procedure for Medium-Size Metal Mines, by A. E. Keller, has recently been issued by the Bureau of Mines.

MINE FINANCING

It is essential that any set-up for financing a mine should be submitted to and discussed with a competent lawyer who is familiar with State corporation and mining laws, taxes, and the various plans for the registration and issue of securities. Clear titles to the property to be financed are also essential, and the questions of water rights, disposal of tailings, mill sites, and railroad sidings solved where necessary before extensive developments are undertaken.

For small groups, where little capital is required, partnerships or syndicates often are formed. In these partnerships or syndicates a single member may be held responsible for the full amount of any indebtedness against the property, regardless of the amount of his interest. To eliminate this responsibility of the individual, stock companies are formed, which may issue assessible or nonassessible stock.

The advantage of a company with assessible stock is to permit mining operations to be started with a small initial capital. When more capital is required this is raised by an assessment and those who cannot or do not wish to pay the assessment may sell their stock or their stock may be debited to the amount of the assessment until sold. Another advantage is that small stockholders cannot be frozen out, as may be done when companies with nonassessible stock reorganize or liquidate.

The advantage of a company with fully paid nonassessible stock is that it is more easily sold to the public, and the owner is free from any liability. In such a company it is important to make ample provision for all capital requirements at the start, as it is only possible to acquire capital later through a loan or the sale of a new issue of stock, which cannot always be done.

Because of the numerous worthless mine promotions and dishonest mine promotors both the investor in mine stock and owner of a prospect are strongly advised to get reliable information on the companies in which stock is offered and the men who wish to promote a new company to acquire capital for the development of a prospect. There are many instances where the property owner has turned over his rights in exchange for stock certificates only to find that the money acquired through the sale of the company's stock has gone into the pockets of the promoters and not into mine developments. Both the public and property owners are protected to some extent in certain States by "blue-sky laws" and recently by the Securities Exchange Commission, but even with these safeguards the greatest caution should be exercised before an interest in a mine is purchased or sold.

Evaluating a Prospect

The prospective investor (not speculator) is interested in the answers to two questions: (1) How much net profit is there in the blocked out ore, and (2) what chance has the prospect to make a mine? The first question can be answered quite accurately after the ore deposit has been sampled carefully and production costs determined, but one cannot express in figures the chance of finding more ore. If the value of a prospect is the net profit on the ore exposed few of them will be found to be worthy of capital investment.

To make a mine, an ore body must be of sufficient size and grade to repay all investment in purchase, development work, and plants, besides all costs of production and interest on capital. If an owner has spent years on his property he often has too optimistic an opinion of its immediate value, and in presenting his prospect for sale he does not always appreciate the necessity for the investor to have a detailed report on the property, with title abstracts, maps, inventories, and (what is of greatest importance) detailed estimates of the tonnage and grade of ore developed. The prospective buyer must have all of this information and much more to be in position to judge the value of the prospect. Good prospects often are not considered, because this information is lacking. If, however, the investors are ready

to send an engineer to make an examination they will first wish to have an option. The owner is thus obliged to place a value on the prospect. Those who will provide capital for development are becoming more willing to send engineers to examine prospects, provided the preliminary information is complete and the price reasonable; but they are not willing to pay for development of a prospect unless it has an exceptional showing. This readiness to devote the services of engineers and geologists and to risk their money in the examination and exploration of a property within a specific time limit should be a sufficient guarantee of good faith to the owner. Investors to-day also expect the owner to have enough faith in his property to be willing to accept payments out of production rather than to insist on large initial cash payments.

Requirements for Obtaining Capital

When it comes to a question of financing, the company or individual to whom the proposal is made will require the following information:

(1) Names and addresses of present as well as former owners of property.

(2) Copies of title record and description of claims or parcels as given in office of recorder.

(3) If property is held under partnership, copy of agreement, or if held under lease, copy of lease.

(4) Complete statement of any mortgages or indebtedness against the property.

(5) Copies of available reports made by engineers or geologists.

(6) Copies of available topographic and geologic maps of the district and a description of the geology of the district.

(7) A recent engineer's report on the property which should include:

(a) A description of the method used in sampling and name and address of the assayer.

(b) Detailed estimates of ore blocked out and assay results.

(c) Estimates of probable and possible ore reserves and supporting data.

(d) Detailed description of the surface and underground workings and their present condition or accessibility.

(e) Inventory of the buildings, plants, and equipment on the property.

(f) Copies of laboratory tests or mill tests of the ore if any have been made.

(g) Records of any ore shipments that may have been made, together with assays, results, and payments.

(h) Information on source, kind, and amount of water supply and nature of water rights; on power supply and cost; on timber supply and costs; on labor supply and wage scale; on housing and living conditions; on transportation facilities and costs; distance to nearest railroad; conditions of roads; and all other information that may help in an estimation of production costs.

Arrangements for Obtaining Capital

Formerly the price demanded for a prospect varied with the locality of the prospect and the mental attitude or financial standing of the owners. Some property owners were modest

and demanded only a nominal sum in cash, while others felt they should have the full value of ore blocked out or even more in cash. Cash sales often were made regardless of value during boom periods, and some purchasers succeeded in realizing a profit. Today owners find it difficult to get even a small cash payment for their property on which they have invested their small fortunes. Investors usually are unwilling to put up cash except for the development work and insist that owners accept a share of eventual returns from mine production for their property.

In the light of the uncertainties inherent in mining, probably the method of financing which is fairest to owners and investors alike is the leasing system, in which the investors agree to furnish funds to develop the property and to pay an agreed royalty on each ton of ore obtained. The lease may be written with or without an option to purchase at a stated price at the end of the leasing period. Such an arrangement indicates that an owner has enough faith in the value of his prospect to be willing to share the risk with the investor. However, in many cases owners have sunk all their capital in prospects and must make a quick sale for cash on which to live. In other words, they have already gambled and feel it only fair that the investors should also gamble to carry on. In such case, an initial cash payment equal to the amount expended by the owners may be justified. On the other hand, the owners may know nothing of mining but feel that their prospects have market value,s because they have been shown to contain ore. They may have had numerous offers to lease but remain skeptical that the lessees intend to do their utmost to make the property productive. They may feel that the lessees wish merely to tie the property up for such time as will enable them to dispose of it to a third party. For these reasons owners often make unreasonable demands for an immediate sale involving an initial cash payment to be followed by regular bonded installments. It is for this reason that many promising prospects lie idle. If owners were willing and able to cooperate with legitimate investors in permitting the latter to give the prospect a fair trial, their chance of remunerative returns would be enhanced.

Information Circular 6774, Leasing System as Applied to Metal Mines, by W. O. Vanderburg, published by the Bureau of Mines in April 1934, gives a clear presentation of the leasing system. In it the bond and lease and straight lease are discussed, the advantages and disadvantages to both the lessor and lessee are presented, the terms or elements for drawing up a lease are given, and the amount of royalties to be paid for various conditions are suggested.

In the leasing system the royalty represents the division of the profit on the ore produced. It is to the advantage of both parties to the contract to make an equitable adjustment of royalty payments. High royalties put a premium on gouging for higher-grade ores and decrease the lessees' incentive to do exploration work. Leasing contracts usually stipulate certain agreements which insure a minimum amount of work or plant installation to make the property productive. By leasing, property owners deal more fairly with lessees than by demanding cash payments, as the risk on investment is minimized. In a straight lease, paying royalty alone, money that would otherwise go to making payments in the face of uncertain conditions may be used for mining purposes.

Mine owners or lessors should stipulate a time limit, granting the privilege of an extension if terms agreed upon are fulfilled; if not, the lease becomes null and void.

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UNITED STATES BUREAU OF MINES
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INFORMATION CIRCULAR

REVIEW OF LITERATURE ON EFFECTS OF BREATHING DUSTS WITH SPECIAL REFERENCE TO SILICOSIS

PART II-A

CHAPTER 4. PREVENTION OF DUST DISEASES
(SECTIONS 1 AND 2)

BY

D. HARRINGTON AND SARA J. DAVENPORT

I.C. 6840
May 1935

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

REVIEW OF LITERATURE ON EFFECTS OF BREATHING DUSTS WITH SPECIAL REFERENCE TO SILICOSIS[1]

PART II-A

By D. Harrington[2] and Sara J. Davenport[3]

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1 The Bureau of Mines will welcome reprinting of this information circular, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6840."

2 Chief, health and safety branch, U. S. Bureau of Mines.

3 Principal translator, U. S. Bureau of Mines.

This circular presents Part II-A of a review of the literature on the prevention of dust diseases; it deals with the principal factors producing pulmonary pathology and methods of determination of dust in air. Part II-B will contain data on the engineering and medical control of dust diseases.

CHAPTER 4. PREVENTION OF DUST DISEASES

Introduction

As no cure is known for silicosis after it has developed, prevention is the only effective remedy. There are two main lines of approach to the problem of dust-disease prevention in industry - the engineering, through control of dust production, and the medical, through selection of workers by examination; success probably depends upon a combination of the two.

Hatch (146) considers the following measures essential to a complete, well-balanced program of control of the dust hazard in industry:

1. Selection of workers by means of physical examinations in order especially to eliminate those with tuberculosis and other disorders of the respiratory system.

2. Reduction of the dust concentration below the standard of permissible dustiness through adequate means of dust control and good housekeeping.

3. Limiting the frequency and duration of employment in the dusty occupations, thus reducing the rate of deposition of dust in the lungs.

4. Routine measurement of the effectiveness of the dust-control program by means of periodic medical examinations and dust surveys.

Of these reduction in dustiness is the most direct in its effect and is fundamental to any program of control. Hatch (146) emphasizes, however, that present-day standards of safety are only estimated values and reduction in dust exposure below the estimated threshold value does not give absolute assurance of complete control of the disease. Moreover, a potential hazard always exists in basically dusty industries, and a constant guard therefore must be maintained. Workers should be selected by physical examination to insure maximum resistance against the action of dust in the lungs. The employment of workers already injured by previous dust exposure thus would be largely eliminated. Routine determination of dust concentrations provides a measure of operation of the dust-control system, but the efficacy of the control program must be measured by periodic medical examination, since only by this means can the presence or absence of silicosis be determined. An inadequate control program thus can be strengthened in time to arrest the widespread development of the disease.

Section 1. - Principal Dust Factors Producing Pulmonary Pathology

The principal factors now thought to determine whether exposure to dust will produce pulmonary pathology are nature of the dust, particle size, quantity of the dust dispersed in the atmosphere, and length of exposure. In

general, it has been held that, other factors being equal, the harmfulness of a quartz-containing dust is in direct proportion to its quartz content. Apparently, then, it is important to ascertain the exact mineralogical composition of any dust under investigation.

Every mineral possesses certain characteristic properties that separate it from other minerals of similar appearance when viewed under the polarizing microscope. These diagnostic characteristics are supposed to persist even to the grains of smallest size; with patience, therefore, the percentage of the various mineral constituents of a dust can be determined (147).

Silica Dust

Free silica or quartz has been considered the outstanding dust factor in industries with excessive mortality from dust diseases. The following summary of information on the chemical properties, occurrence, and industrial uses of silica is taken from A Review of Silicosis by Adelaide Ross Smith (148).

Chemical properties of silica.- Silica has the chemical formula SiO_2, indicating that it is a combination of the element silicon (Si) and oxygen (O). It occurs alone in the "free" form and, as such, is variously known as silicon dioxide or "free" silica. In combination with other elements it is known as "combined silica", but this report is concerned with free silica especially because in this form it causes more damage to the lungs than when it is in the combined state.

Free silica (silicon dioxide) may be either crystalline or noncrystalline (amorphous) in structure. Crystalline silica, which is usually quartz, is a white or colorless, extremely hard substance ordinarily with a specific gravity of 2.66. When heated for a long time at about 1,000° C. it forms a second variety known as "tridymite" with a specific gravity of 2.33; a third variety, cristobalite (specific gravity 2.34), occurs when quartz is heated for periods not long enough to form tridymite. Noncrystalline (amorphous) silica occurs as a fine white powder.

Silica assumes the vitreous, molten form more easily than any other mineral substance, melting to colorless quartz glass in the oxyhydrogen blowpipe at about 1,600°. The coefficient of thermal expansion of quartz glass is very small, so that it possesses in a high degree the property of being able to withstand rapid cooling without cracking.

Silica is chemically inactive at ordinary temperatures but at high temperatures acts as an acid anhydride and combines with the bases and many metallic oxides to form silicates. When soluble alkaline silicates are treated with acids silicic acid, an amorphous gelatinous substance, is obtained. This is soluble in water and acids and is readily dissolved by dilute solutions of alkali hydroxides and carbonates.

Occurrence of silica in nature.- Silica is one of the most common minerals. In one form or another it constitutes approximately 60 percent of the earth's crust and forms whole mountain ranges in certain countries.

Examples of free silica in the pure crystalline form are quartz and rock crystal, but many other minerals whose essential composition is quartz have been changed in color or form by the addition of small amounts of other substances, usually oxides of other elements. Many of these are used chiefly for ornaments and jewelry; but some, such as buhrstone and flint, have important industrial uses as well. These quartz rocks include the following: Agate, aventurine, amethyst, bloodstone, brazilian pebble, buhrstone, carnelian, cat's-eye, chalcedony, chert, cairngorm, chrysoprase, certine, flint, hairstone, hyalite, jasper, jaspilite, lydian stone, milk quartz, needlestone, onyx, opal, plasma, phrase, rose quartz, sard, smoky quartz, and tiger's-eye. Common rocks containing a high proportion of free silica are: Sandstone, essentially grains of quartz with some feldspar, mica, and other materials added, quartzite, a product of sandstone; ganister, a sedimentary rock with a very high percentage (about 98 percent) of free silica; granite, composed essentially of quartz and feldspar, containing 25 to 35 percent of free silica; and pegmatite, a form of granite. Ordinary sand is almost entirely quartz.

Amorphous (noncrystalline free) silica forms opal and is associated with quartz in certain other stones, such as chert, flint, and chalcedony. It is represented chiefly by diatomaceous earth and tripoli or rottenstone.

Diatomaceous earth is a soft, earthy rock composed of the skeletons of small aquatic plants resembling chalk in appearance. It can hold four times its weight of water and is a poor conductor of heat, sound, and electricity. Tripoli is a porous rock which results from the natural decomposition of sandstone.

Combined silica (silicates) occurs in almost every rock species and forms the essential substance of such common materials as clay, mica, feldspar, and slate.

<u>Industrial uses of silica</u>.- Silica has many properties of industrial value: Hardness; resistance to solution (even in acid), heat (under some conditions), and temperature changes; and crystalline and decorative properties. In the amorphous form it is also valuable as a filtering medium and nonconductor.

It is used in a variety of different forms, in the massive form both roughly broken and cut to different sizes and shapes; in the original condition as pebbles or as grains; crushed to a coarsely granular form or ground to a fine powder. Its chief uses and corresponding forms have been tabulated by Smith (148) from Ladoo as follows:

Abrasive uses, in scouring and polishing soaps and powders - quartz, quartzite, flint, chert, sandstone, sand, tripoli, and diatomaceous earth, all in finely ground state; in sandpaper - quartz, quartzite, flint, sandstone, and sand, coarsely ground and closely sized; in sand-blast work - quartz, quartzite, sandstone, and sand, crushed into sharp angular grains uniform in size; metal buffing, burnishing, and polishing - ground

tripoli and other forms of ground silica; for sawing and polishing granite - sharp, clean sand graded into various sizes; as whetstones, grindstones, buhrstones, pulpstones, oilstones - massive sandstone from very fine- to moderately coarse-grained; tube-mill lining - chert, flint, and quartzite in dense, solid blocks; lithographers' graining sand - medium to fine sand or rather coarsely ground silica and tripoli; tube-mill grinding pebbles - rounded flint pebbles; in tooth powders and paste - various forms of pure silica finely ground; wood polishing and finishing - all forms of silica ground to medium fineness. Refractory uses, in making silica fire brick and other refractories - fairly pure quartzite known as ganister, not less than 97 percent SiO_2 nor more than 0.40 percent alkalies, tightly interlocking grains desired. Metallurgical uses, in making silicon, ferrosilicon, and silicon alloys of other metals, as copper - moderately pure sand, massive crystalline quartz, sandstone, quartzite, or chert; as a flux in smelting basic ores - massive quartz and quartzite; foundry-mold wash - ground sandstone, quartz, and tripoli; foundry parting sand - fine sand and ground tripoli. Chemical industries, as a lining for acid towers - massive quartz or quartzite; as a filtering medium - massive diatomaceous earth and tripoli, sand, finely granular quartz or quartzite, finely ground tripoli, and other forms of silica. In the manufacture of sodium silicate - pure pulverized quartz sand, pure tripoli, and diatomaceous earth. In the manufacture of carborundum - pure quartz sand. Paint, as an inert extender - finely ground crystalline quartz, quartzite, and flint, also finely ground sandstone, sand, and tripoli. Mineral fillers, as a wood filler - finely ground crystalline quartz, quartzite, flint tripoli, and other types of ground silica. In fertilizers and insecticides - finely ground crystalline quartz, quartzite, flint, tripoli, and other types of ground silica. As a filler in rubber, hard-rubber pressed and molded goods, phonograph records - finely ground silica of all types. In road asphalt surfacing mixtures - finely ground silica of all types. Ceramic uses, in the pottery industry as an ingredient of bodies and glazes, flint, tripoli, and chert (amorphous silica preferred), also all other forms of very pure silica, all finely ground. Building stone - cut granite and sandstone. Monuments, paving blocks - cut granite. In the manufacture of ordinary glass - pure quartz sand; in the manufacture of fused-quartz chemical apparatus, as tubes, crucibles and dishes - very pure massive quartz preferred. Decorative materials, in the manufacture of gems, crystal balls, table tops, vases, statues - rock crystal, amethyst, rose quartz, citrine quartz, smoky quartz, chrysoprase, agate, chalcedony, opal, onyx, sardonyx, jasper. Insulation, heat insulation for pipes, boilers, furnaces, kilns - massive and ground diatomaceous earth; sound insulation in walls, between floors - massive and ground diatomaceous earth. Structural material, sand-lime brick - moderately pure, sharp, angular sand, preferably finer than 20-mesh, together with a small percentage of finely pulverized silica, optical quartz, for the manufacture of lenses and accessories for optical apparatus - clear, colorless, flawless rock crystal or massive crystallized quartz.

Sericite.- In 1926 Mavrogordato (149) remarked that -

> The increasing use of the term "silicosis" implies the recognition that in industry this disease is particularly related to inhalation of dust of free silica (SiO_2); in fact it is doubtful if it occurs apart from free silica, or, anyhow, the intractable silicates, for example, sericite.

The mention of sericite by Mavrogordato is interesting in connection with the relatively recent statement by Jones (150) that sericite, not silica, causes silicosis. He explains the circumstances which caused him to reach this conclusion:

> During the last 20 months I have had occasion to visit a number of collieries in the anthracite district of the South Wales coal field with the object of collecting, from the former working places of underground employees who had contracted silicosis in the course of their employment, samples of rock which could be proved to come under the category of "silica rock" as defined in English law, for the purpose of compensation under the Silicosis Schemes. It should be explained here that, whereas under your (South African) mining law an employee who is certified as having contracted silicosis in the course of his employment in your gold mines, receives compensation without further legal proceedings, English law, on the other hand, demands proof, in the case of underground workmen in collieries, that the employee has been working in "silica rock", that is, in quartz, quartzite, sandstone, gritstone, or chert. In the majority of cases I was able to find samples of rock that fulfilled the legal definition of "silica rock", but in some, even when post-mortem examination had revealed silicosis and where the former working places of the deceased were accessible, it was not possible to find rock of the type included in the Silicosis Scheme. These cases, and there were several of them, naturally aroused my interest, for they appeared to make clear the possibility that rocks other than those included in the Silicosis Scheme could give rise to dangerous dusts. I decided to investigate the matter.

Jones (151) summarized the results of his investigation as follows:

> The result of these investigations on the mineral residues obtained from 29 silicotic lungs and of the examination of the rocks and materials which gave rise to the inhaled dusts causing these cases of silicosis lead to the following conclusions:
>
> 1. The bulk of the mineral residues obtained from every silicotic lung investigated by the author consists of minute fibers of the mineral sericite, a hydrated silicate of aluminium and potassium known also as "secondary white mica." This mineral is abundantly present also in all the rocks and materials which gave rise to the inhaled dust, and it is present in these rocks and material in minute fibers and scales of the size it is found in the residues and also in the lung tissue.

2. Silica in the uncombined state, as quartz, is also present in these residues as relatively coarse and fine grains; it occurs, however, in amounts subordinate to sericite. Especially is this so with regard to the small number of quartz particles, as compared with the countless fibers of sericite.

3. One relatively large grain of quartz, measuring 10 by 8 by 5 microns, such as is found in the residues, is equal in volume to 800 fibers of sericite measuring 2 by 0.5 by 0.5 microns and contributes as much silica in the chemical analysis of a residue as would 16,000 fibers of sericite. This would appear to be out of all proportion to the silicotic effect of one such quartz grain in the bronchi and bronchioles, compared with the effect in the alveoli of hundreds of fibers of sericite.

4. Silica in the uncombined state, as quartz, is not the chief cause of silicosis in these and certain other cases. This appears to be conclusively established, it is submitted here, by the following facts: (a) The amount of quartz and the size and form of the quartz grains in the sandstones occurring in the underground working places in the Scottish coal fields and in the South Wales coal fields are alike. The latter sandstones give rise to dust that has caused scores of cases of silicosis, whereas no authenticated case of silicosis has been produced in the Scottish coal fields. (b) The gold-bearing quartz conglomerate of South Africa gives rise to dust that has caused thousands of cases of silicosis; the gold-bearing quartz rock of the Kolar golf field, India, contains more quartz than the South African rock and yet produces dust that has caused no case of that disease. (c) No quartz-bearing rocks investigated by the author are known to have given rise to silicosis-producing dust except those which also contain abundance of fibrous aggregates of sericite or of fibrous silicate minerals, loosely held together and easily freed into the atmosphere when the rock is drilled and blasted. (d) Rocks which contain a relatively small percentage of quartz (well below the minimum amount in the rock types named in the Silicosis Schemes under English law), but which do contain fibrous silicate minerals such as sericite and sillimanite - as, for example, at Broken Hill mines, New South Wales - produce dust that has caused a large number of silicosis cases.

5. These investigations are not concerned with the pathological condition produced by the minerals in the lungs. Whether they merely act as mechanical irritants causing the growth of fibrous tissue, as advocated by some well-known authorities, or induce chemical changes, as maintained by certain eminent pathologists, is a question entirely beyond the province of the author. His conclusions do not militate against either theory; on the contrary, they provide the former school with evidence of the presence in the lungs of thousands of acicular fibers that presumably could act as mechanical irritants and the latter school with evidence of the presence of silicate minerals less stable than quartz and which, because of their physical form, expose far greater surface to volume for any chemical action than do the more compact grains of quartz.

> 6. Lastly, it is submitted that it is mainly the presence in the exploited rocks and materials of fibrous minerals, be they sericite, sillimanite, tremolite, etc. (or a fibrous form of free silica in chert, or of a fibrous rock as in pumice), in aggregates which, during the impact of drilling, blasting, or crushing, become freed into the atmosphere as individual fibers, that enables sufficient material in course of time to enter the lungs to cause silicosis. It is not suggested that sufficient minute particles of quartz could not, under any circumstances whatever, enter the lungs to cause silicosis, although the cases hitherto investigated appear to show conclusively that they have not done so; but it is maintained that the fibrous minerals hasten the process so very considerably that their presence in the exploited rocks and materials is of far greater importance in causing this disease than is the presence of quartz.

The statement by Jones that sericite rather than silica dust is the cause of silicosis aroused considerable discussion among those interested in the question. In September 1933 Jones (152) presented a paper before the Chemical, Metallurgical, and Mining Society of South Africa in which he said:

> I submit, therefore, that the mineral residues I obtained from silicotic lungs (and this applies to all those I have so far investigated) show definitely that it is not quartz, or any kind of free silica, that forms the bulk of these residues; and I suggest that silicosis is not mainly due to free silica, as has hitherto been accepted, but to silicate minerals occurring in the form of minute fibers loosely held together in the rocks so that, during handling, drilling, and blasting, they are readily freed into the atmosphere and inhaled into the lungs. * * *.
>
> It is clear, therefore, that hitherto no acceptable explanation has been given why the inhaled dust of your South Africa quartz-bearing rock is so extremely dangerous in its silicotic effect and why the dust of the Indian rock, with still more quartz, has not caused a single case of silicosis. The real explanation I submit, is simple: Whereas in the South African rock there are, between the quartz pebbles and quartz grains, aggregates of minute acicular fibers of sericite, hundreds of which fibers can be seen in microscope sections of this rock, such acicular fibers are absent from the Kolar quartz rock or very rare. The quartz grains in the Kolar rock are interlocking: there is no fibrous mineral to be seen between the sharp boundaries of the individual grains. Between the quartz pebbles and the quartz grains in the "banket", acicular crystals of sericite are very abundant; in fact, sericite ranks next to quartz as the most common mineral in your gold-bearing quartz conglomerate. It is not suggested here that all the sericite present is in fibrous form; much of it is in the form of minute scales, but the point is that countless fibers of this mineral do occur throughout this rock. * * *.

There is one other outstanding case which will be referred to here because it has features of peculiar interest; it is that of the Broken Hill mines, New South Wales, Australia. Many cases of silicosis have

been diagnosed amongst the Broken Hill miners where "in 8 years 160 mine workers were withdrawn as suffering from simple silicosis" and where in a similar period "of 101 men classified as suffering from silicosis plus tuberculosis there were living only 15; 86 percent had died." The amount of free silica in the Broken Hill ore (and the ore bodies, be it noted, are very wide) varies from 1.62 to 17.73 percent; and in the "country rock" it averages under 20 percent free silica. In some of the mining blocks at Broken Hill, where cases of silicosis have occurred, there is no rock which could be included under any of the types of rock named in the Silicosis Schemes in English law, yet dust has been produced that, as stated, has given rise to scores of cases of this disease; that in itself is a fact full of significance. At Broken Hill, however, occurs a rock known as "sillimanite gneiss", in which the aluminium silicate mineral, sillimanite, occurs sometimes in large crystals but generally as minute fibers; in fact the alternative mineralogical name of sillimanite is "fibrolite" because it so commonly occurs in fibrous form. Sericite is also abundantly present in some of the Broken Hill rocks. Here then we have rocks low in their content of free silica, but containing fibers of sericite and sillimanite, which produce dangerous dusts.

Attention was drawn to the low content of free silica in the Broken Hill ore and adjacent rocks by Dr. R. R. Sayers in 1925 and by Drs. Charles Badham and W. E. George of New South Wales at the International Conference in 1930. It is of particular interest to note also that at the Conference the possibility that silicates may have played a role in the causation of silicosis was not entirely overlooked although it seems clear from the definition accepted at the final sittings (that the disease was caused by silica in the uncombined state) that their effect was underestimated. Dr. E. L. Middleton pointed out that "silicates would, sooner or later, have to be studied systematically as the cause of pulmonary disease in industry. There is abundant evidence already that the silicates cannot be regarded as a single group showing a uniform effect on the pulmonary tissues and producing the same results of disablement and death of those affected." Dr. Badham, also at the Conference, stated that "he was by no means convinced that the silica was the whole story of their disease. He found confirmation of that view in the fact that where they had, as in Broken Hill, 85 percent of silicates, most of them intractable, they found in the lung after death intractable and other silicates. It was therefore reasonable to assume that silicates had a considerable effect on the production of fibrous pneumonoconiosis."

Brief reference will now be made to the clays used in the manufacture of pottery. The "clay body", consisting largely of kaolin (china clay) formed from the decomposition of felspar, contains fibers of sericite. * * *. These readily become freed into the atmosphere from the dried clay.

In discussing the above paper Irvine (153) said that the fact that this very important contribution to the subject had been so long delayed was a

forcible illustration of the sometimes unfortunate results of the division of science into more or less independent special professional department - the division was necessary but apt to be to some extent harmful, as the mineralogists, chemists, mining engineers, pathologists, and other medical men, in general, know very little about each other's business. He then summarized the history of the silicosis question from this aspect:

When, 30 years ago, interest was awakened or re-awakened in the problem of "miners' phthisis" by the recognition of its prevalence on the Rand, in Cornwall, in Australia, and elsewhere, it was looked upon in this country as purely an affair of gold mining on the Rand. And when we were told by the mineralogists and the chemists that the Rand banket was composed of 80 to 90 percent of free silica and the remainder of silicates, pyrites, and small quantities of other minerals, we were satisfied with this account, because it was at that time accepted all over the world that free silica was the agent wholly or mainly incriminated. Not only so, but it was also accepted that the gold mines of the Rand were the only significant producers of silicosis in South Africa. I am not aware that any petrologist until now has ever questioned the free-silica hypothesis or has seriously contributed to an exact solution of the undoubted difficulties which that hypothesis was later on found to present. Probably they may say that they were not asked; if so, the more was the pity on both sides. In any case the free-silica tradition held unquestioned sway for many years all the world over.

When Doctor Pitchford and R. Moir in 1916 published their paper on the mineral content of silicotic lungs they were perfectly well aware that both the banket and silicotic lungs contained sericite. But, probably under the influence of the silica tradition, they appear to have underestimated the proportion of sericite in the lungs, and they overlooked the possible pathological importance of its presence.

Then there followed a middle period during which, with a more extensive knowledge of silicosis-producing industries, certain difficulties in the free-silica tradition became increasingly apparent. Why was it that certain rocks which had a high free-silica content did not appear to produce silicosis, while others with a much lower silica content did so? The first answer suggested to that question was that associated in particular with the honored name of Dr. J. S. Haldane, namely, that the apparently innocuous rocks contained other constituents which were in some way antidotal to the action of silica. Then there came further obstinate questionings. "Was silica after all the whole story of the disease?" Was it not "reasonable to assume that silicates had a considerable effect in the production of fibrous pneumonoconiosis?" The Australian delegates to the Silicosis Conference in 1930, in particular (and notably Doctor Badham), voiced this suggestion. The radiographs of cases of silicosis from Broken Hill in Australia could be matched point by point with radiographs of Rand silicosis. Yet the silica content of Broken Hill ore is decidedly low and in parts extremely low. This made one think, but, as the journalists would put it, apparently we did not at the Conference think quite "furiously" enough. Journalists, I notice, always think "furiously."

And now with Doctor Jones comes apparently a third period. He has supplied at long last and and for the first time an exact, direct, and extensive petrological attack upon the problem, and his results appear to show that we may have to turn the problem right round in order rightly to understand it. It is not the presence of "antidotal" substances along with silica in the innocuous siliceous rocks, but the presence of fibrous mineral silicates such as sericite and sillimanite in the harmful rocks, which is, on his hypothesis, the solution of the puzzle, while the actual proportion of free silica present is of relatively lesser importance. Apart from the very strong direct evidence which Doctor Jones adduces, a considerable degree of prima facie support for his view is obtained from the fact that asbestos, also a fibrous silicate, is known producer of a pulmonary disease analagous to but not quite identical with silicosis.

Irvine was not sure whether anyone had proved conclusively that a true noninfective silicosis had been produced experimentally by inhalation of pure quartz dust, nor did he know whether sericite could readily be separated mechanically from its admixtures with quartz and other minerals. Mavrogordato (154) said that when he started working on this subject in Doctor Haldane's laboratory he used finely ground pure silica to produce a perfectly good silicosis in animals. He was particularly interested in Jones' hypothesis that the ordinary processes of rock-breaking and handling yielded only a small porportion of quartz particles of phthisis-producing size; this might account for the fact that he (Mavrogordato) produced silicosis in animals with finely powdered quartz artificially prepared. It was not suggested by Jones (155) that sufficient minute particles of quartz could not, under any circumstances whatever, enter the lungs to cause silicosis, although the cases investigated appeared to show conclusively that they had not done so; but it was maintained that the fibrous minerals hastened the process so very considerably that their presence in the exploited rocks and materials was of far greater importance in causing the disease than the presence of quartz.

Mitchell (156) questioned Jones' statement that dust from rocks that contained no sericite had never caused silicosis and quoted from the literature cases in which exposure to silica dust that contained no sericite or only a small amount had caused the disease. One industry, in which the dust contained 96 percent SiO_2 and only 4 percent alumina potash, had an annual mortality of 7.71 per 1,000 from phthisis and pulmonary fibrosis; the material used in this industry, Mitchell said, apparently was of the very type which Jones claimed had not caused a single authenticated case of silicosis. Mitchell also made the following statement regarding the examination of biscuit placers and fettlers in the pottery industry, as reported in the literature:

> As far as I have been able to determine, the fettlers work with a mixture of clays, china clay, felspar, etc., material which is, to a very great extent, made up of the hydrated silicate of aluminium.
>
> Doctor Jones, in fact, states that in china clay fibers of sericite are numerous and that they readily become freed into the atmosphere from dried clay.

The biscuit placers, on the other hand, work with a very finely ground flint, that is, with material which is almost pure silica (98 percent SiO_2 in an extremely fine crystalline condition).

Doctor Jones has submitted that silicate and not silica is the main cause of silicosis and I find it difficult to reconcile this submission to the fact that silicosis is very prevalent amongst the biscuit placers, who work in an atmosphere containing much less silicate and far more silica than the atmosphere breathed by fettlers.

If silicates and not silica were the main cause of silicosis, then why the apparent immunity of the fettlers from the disease?

I understand that one of the silicotic lungs examined by Doctor Jones was that of a china biscuit placer and I presume that, in that case, as in all others, he found a very high percentage of silicates. A chemical analysis of the air in that process shows a low percentage of alumina and potash and a high percentage of silica. This, together with the fact that the material worked with is almost pure silica, naturally causes one to wonder as to the source of silicates he found in the lung. I have no doubt that Doctor Jones, in a very simple manner, will be able to explain the apparent anomalies to which I have referred.

Flugge-de Smidt (157) emphasized the importance to engineers of Doctor Jones' discoveries as follows:

Doctor Orenstein, in proposing a vote of thanks, did not seem to realize the practical importance of Doctor Jones' discoveries. Except in the matter of the elimination of the unfit, the medical fraternity cannot claim very much credit for the reduction of the incidence of phthisis. It is the mining engineer who, mainly through increased ventilation, has been responsible for the betterment of our conditions and to the mining engineer Doctor Jones' investigations are of the greatest practical importance in the problems of dust determination and dust prevention.

According to Ranson (158), the results of Doctor Jones' investigation on the causation of silicosis have clarified the anomaly of certain ore bodies carrying a high percentage of quartz having no apparent deleterious effect on the worker and a deposit with a similar quartz or silica content readily producing silicosis. He said:

Doctor Jones in his investigation adopted new and original methods, and it has to be admitted that in advancing the theory that sericite crystals or fibers are the principal cause of miners' phthisis or silicosis he has put up a very convincing case. At the same time it is difficult to imagine that such a phenomenon was not generally recognized, when one considers the renowned workers and investigators we are fortunate in having here who have spent many years in thoroughly examining every phase of the subject.

The presence of silicates in the Rand banket is generally well-known and I believe it is also recognized that the percentage tends to increase steadily from west to east along the reef. It has been the general belief that such dust particles played no part in the development of silicosis and that minute particles of free silica were the primary cause of the disease.

The findings of Doctor Jones may not be generally and immediately accepted as conclusive, but they have opened up additional avenues of research which may lead to finality in determining the principal cause of miners' phthisis on the Rand.

Stokes (159) wondered, as did Flugge-de Smidt, whether Orenstein had been adequate in his appreciation when proposing a vote of thanks to Jones. According to Orenstein, Jones had added one more stone to the structure upon which the efforts against phthisis had been built. Stokes suggested that in addition to giving them that extra stone Jones, first of all, had had to demolish a wood and iron structure of scientific fallacy - the free-silica fallacy - which had been accepted for 40 years.

Truter (160) introduced another point of discussion:

> The sericites or free silica are, we believe, the primary cause of silicosis. I have examined miners for many years and have come to the conclusion that besides the sericites and free silica there are also other factors at play that cause the disease of silicosis.
>
> My reason for making this statement is: Why should two men work under the same conditions underground, the one contract silicosis after 2 years and the other not after 14 years? This is very difficult to understand, unless there are also other factors along with sericite and free silica that produce silicosis. One man I examined worked for 29 years underground on the Reef, 27 years of which period he worked on machines (machine work is considered to be most productive of the disease silicosis). This man was old and by no means fit. I would have liked to have been able to recommend him for compensation. I had him X-rayed and re-X-rayed but could not prove that he even had the slightest beginning of silicosis. On the other hand I examined a man who spent 2 years underground, left the mines, was out of the mines for the following 5 years and at the end of that time had a definite silicosis.

Such histories are by no means as rare as imagined.

> As I said, this is difficult to understand, unless there are some other factors combined with free silica or sericite which go to assist to establish the disease. Are these factors mechanical, physiological, pathological, or what? For these reasons the scientific bodies should combine and try and solve the question of "prevention of silicosis."

Jones (152) responded that Irvine, Mavrogordato, Orenstein, Simpson, and Strachan agreed that the great bulk of the dust found in the silicotic lungs of Rand miners consists of minute acicular fibers and asked:

> What are these thousands of mineral fibers that are so conspicuous in the sections of silicotic lungs and in the residues obtained from them, when these are examined under the petrological microscope? * * *. Petrological examination of the fibers in the silicotic lungs of Rand gold miners shows clearly that they are sericite.

With regard to Mitchell's reference to the literature, Jones (152) suggested that references to minerals by medical authorities should always be checked by the examination of such minerals under the petrological microscope, as otherwise mistakes would be perpetuated.

In the discussion of a similar paper presented by Jones before the Institution of Mining and Metallurgy in London in January 1934 Haldane (115) dissented most emphatically from the conclusions drawn by Jones. Haldane pointed out that what seemed to him to constitute perfectly clear evidence incriminating uncombined silica was not the nature of the dust found in the lungs at death, but the history of prolonged exposure to dust containing a high proportion of uncombined or free silica. He found nothing to indicate that either the presence or absence of sericite had anything especially to do with the silicosis produced by quartz, while the evidence incriminating dust with a high percentage of quartz was overwhelming. Although he had once attributed the harmlessness of diluted free silica to a special quality of the diluent dust, Haldane said he had been converted by the experiments of Gye and Kettle - which indicated that the dissolved silica had positive detrimental effects - to the opinion that it was the action of the silica and not the absence of positive action of other dust that was important. He explained the presence of sericite in the silicotic lung as due to the fact that free silica dissolved gradually in an alkaline liquid, while natural silicates were much less soluble. The very small particles of free silica would therefore disappear more quickly in the living lungs, leaving silicates and only relatively large particles of free silica, as Jones had found. The free silica if in sufficient concentration and in a fine enough state of division in the phagocytic cells went into solution in their slightly alkaline medium and in so doing paralyzed their activity in both removing dust and handling tubercle bacilli, but if sufficiently diluted with other dust of any kind it would do no harm. At death nearly all the finely divided silica would have dissolved, leaving a residue of natural silicates and only relatively large particles of free silica. Haldane claimed that the smaller particles which had disappeared had done the real damage, not the large particles. Kettle (115) admitted that sericite might be responsible for a great deal of industrial silicosis, but he was not very much impressed with Jones' negative evidence that silicosis was not contracted where sericite was not present. It seemed to him to be going much too far to suggest that silica itself was incapable of producing the disease; conditions in the mines or in the various factories might interfere with the entrance of dust into the lungs, and the anomalous distribution of silicosis might depend on some such factor. He said the question of the solubility of silica was of great importance; there could be

no doubt that a too readily soluble silica was just as incapable of producing lesions of silicosis as an absolutely insoluble silica. It had been shown that these lesions could be produced by the intravenous inoculation of crystalline silica; also in his laboratory the intravenous inoculation of amorphous silica had proved incapable of producing these lesions; such evidence indicated the complexity of the whole process. In conclusion, he stated that in his opinion Jones had presented a very strong case in support of his view that sericite was responsible for a great deal of industrial pneumoconiosis.

According to Industrial Medicine (161), a number of opportunities to examine samples of dust for sericite fibers have been presented in the United States. When examined petrographically samples of material collected where a great deal of drilling was being done through siliceous rock did not show an appreciable amount of sericite material, although it was definitely known that silicosis occurred by exposure to this type of dust. A recent report issued by the Commonwealth of Massachusetts (101) relative to the findings of the Special Industrial Disease Commission also mentioned the examination of samples of different types of granite and foundry dusts. In certain petrographic examinations sericite was not found, in others it was found in very small quantities, and in additional samples the amount was appreciable. Although no general conclusion was reached the petrographers believed that in industry sericite could be avoided more easily than quartz.

The October 12, 1934, issue of the Colliery Guardian (162) quotes Irvine to the effect that "the apparent negative instances from the Mysore (Indian) gold field and the Lonely mine in Rhodesia are neither of them convincing, because neither so far has been adequately investigated." At one time it was said that there was no disabling silicosis in Cripple Creek in the United States; however, according to Russell (163), silicosis undoubtedly occurred there, but the miners who developed the disease left as soon as the altitude began to trouble them, and their deaths were recorded elsewhere.

Early in 1934 the Mysore Government appointed a special committee, consisting of the chief medical officer of the Mining Board Kolar Gold Fields, the local medical officer of the Mysore Government, and the physician of the Krishnarajendra Hospital, Mysore, to investigate the prevalence of silicosis among the miners on the Kolar gold-field area (164). The committee conducted a preliminary investigation and unanimously concluded that silicosis does occur among the underground workers but that the incidence of the disease in the field is much smaller and a much longer time is required to develop signs and symptoms than in South Africa. This difference evidently is due to the fact that Kolar rock contains only 5 to 20 percent of free silica, whereas the South African samples contain 43 to 98 percent. Under the circumstances Irvine, of South Africa (164), has felt it necessary to contradict the statement that "in the Kolar gold field, India, where the rock contains a large amount of quartz and sericite is absent, silicosis has hitherto inexplicably been unknown."

<u>Properties of sericite</u>.- According to Jones (<u>152</u>), sericite, sometimes called "secondary white mica", is a hydrous silicate of aluminium and potassium containing (analysis of specially selected pure material) 46.53 percent SiO_2, 37.46 percent Al_2O_3, 0.80 percent Fe_2O_3, trace of CaO, 1.16 percent MgO, 6.38 percent K_2O, 0.64 percent Na_2O, 6.06 percent water above 110° C., and 0.30 percent water below 110° C. He said that sericite is most common in rocks that contain a high percentage of free silica in the form of quartz but is not present in all rocks that contain quartz; that the dust from rocks that contain abundant sericite as aggregates of acicular fibers has been proved to cause silicosis; and that the dust from rocks that contain no sericite or only occasional crystals of it but which contain a very high percentage of quartz - as high or higher than the rocks that had proved dangerous - apparently has not caused a single authenticated case of silicosis.

<u>Carbon dioxide theory</u>.- An article in the Canadian Mining Journal for September 1934 called attention to the interesting theories and facts brought out in the discussion of Doctor Jones' paper on sericite as a cause of silicosis. Edge's (<u>165</u>) theory is based on the liquid inclusions in quartz and other minerals, a fact known to petrologists for many years but one that has received little attention. Edge examined carefully specimens of quartz from mining districts where silicosis is prevalent and found that the quartz of these regions carries liquid inclusions, while that of areas free from silicosis carries very little; he therefore suggests that this fact may have some bearing upon the disease. The journal discusses the matter as follows:

> The remarks of Mr. Edge on milky quartz from the Hollinger are of more than ordinary interest. He points out that, as expected, the microscope revealed that the whiteness of the quartz was due to the reflection of light from immense numbers of minute cavities, each containing liquid and a gas bubble. In the Hollinger quartz he found that the number of the visible cavities per cubic millimetre was of the order of 1,000,000, being seldom less than 200,000, and rarely more than 3,000,000.
>
> He goes on to say "many of the cavities were found to contain two immiscible liquids as well as a gas bubble, the latter incidentally being kept in a perpetual state of agitation by the Brownian movement of the gas molecules within it. Of the two liquids, one was easily identified as liquid carbon dioxide by means of its critical temperature (31° C.). The other liquid appeared to be water or an aqueous solution of some kind."
>
> Naturally, with the presence of liquid carbon dioxide established, it was easy for the investigator to deduce the pressure existing in these cavities for any particular temperature. Thus, if a piece of this quartz was placed in the mouth for a few moments its temperature would be raised to that of the body (37° C.), which is 6° above the critical temperature of CO_2.
>
> It follow, therefore, that, with the quartz subject to body temperature, all the contained CO_2 would be in the gas phase, and by referring to tables of physical data, it immediately becomes obvious that the

pressure within the cavities is in the vicinity of 84 atmospheres, which is more than half a ton to the square inch. Mr. Edge points out that "furthermore, if the pressure were suddenly released, say by the solution and ultimate bursting of the walls of a cavity, the compressed CO_2 would expand almost instantaneously to about 400 times the volume which it occupied within the cavity. In fact, some of the quartz specimens examined contained between 3 and 4 times their own volume of CO_2 if the latter were released to conditions of normal temperature and pressure."

Mr. Edge found similar conditions in the quartz of the Rand. As he points out, quartz particles taken into the human lung can contain a great number of these cavities, and there is some interesting food for thought in speculating upon exactly what happens if these particles are disintegrated and discharge their gases under pressure into the surrounding tissue. Mr. Edge does not advance these possibilities very far; but his work on the liquid inclusion of milky quartz is very interesting and may present another field of investigation.

Irwin (166) reports the following results of investigations carried out at the Banting Institute (Toronto, Canada):

> Since little or no silicosis was observed in workers on the crushers of gold and other mines, it was subsequently suspected that the gases in the mine atmosphere might prove to be an important factor accelerating silicosis, and experiments were carried out in which such gases as sulphur dioxide and nitrous oxide were used in minute proportions. Later, when Dr. W. R. Jones suggested that sericite and not quartz was responsible for miners' fibrosis, it was decided that the workers at the Banting Institute should perform their experiments in three groups. The effects were observed on animals in: (1) An atmosphere containing mine gases alone; (2) an atmosphere containing mine gases and quartz dust; (3) an atmosphere containing mine gases and sericite dust. From these experiments it seemed doubtful whether real silicosis was initiated, since no definite lesions were noted in the lungs.
>
> The following conclusions had been drawn during the investigations: (1) That all people aggregated a cumulative amount of silica in certain organs, from birth to old age, and that if a man lived to, say, 200, he would probably resemble a silicotic case; (2) that silica was fairly soluble in the body and that the organs of excretion threw off a certain amount; (3) that the gases used in their animal experiments damaged the organs of excretion, and thus a higher amount of silica was retained by the animal; (4) that the mineral particles in the lung revealed by the microscope played little or no part in the acceleration of silicosis, but that the fibrosis was caused by some form of "easily soluble silica", probably introduced in extremely minute form.

Nature of silica dust.- Research in the field of dust inhalation appears to have demonstrated that, in general, the degree of health hazard associated with the inhalation of any dust, all other factors remaining constant, depends upon the mineral composition of the dust. Knopf (167) states that the harmfulness of a quartz-containing dust usually is in direct proportion to its

quartz content; therefore, in an attempt to evaluate the harmfulness of a dust it is of great importance to ascertain its exact mineral composition.

A long-established convention has led to the reporting of chemical analyses of rocks and minerals in terms of certain chemical compounds (usually oxides) rather than in terms of chemical elements (167). During analysis the silicon is isolated in the form of silica; consequently the chemical analysis of an average granite, for example, is reported as containing 70 percent of silica. About 30 percent (roughly one third) of the entire granite is quartz, whereas the other two thirds of the granite comprises chiefly complex mineral salts of silicon-bearing acids; such minerals are known as silicates. The remainder of the silica reported in the chemical analysis of granite (40 percent) is locked up in these silicate minerals, chiefly feldspar and mica.

This arbitrary convention of reporting rock and mineral analyses in terms of oxides has necessitated the use of the expressions "free silica" and "combined silica" to distinguish the silica that makes up quartz (or the few other minerals that are composed of silica alone) from the silica combined with other elements in the various silicate minerals (167). In the granite cited the 70 percent total silica is the sum of 30 percent free silica and 40 percent combined silica.

According to the Industrial Health Section of the Metropolitan Life Insurance Co. (168), although obviously dust containing 90 percent silica is more harmful than dust containing 60 percent, it is not known whether the relative harmfulness is one of strict arithmetical proportion.

The argument whether the cause of the lung condition called silicosis is due to free silica or to sericite has not been settled. With white mica dust Policard (169) produced experimentally pathological lung changes identical with those produced under the same experimental conditions by inhalation of various siliceous rock dusts, such as sandstone. He assumes that in the latter case the noxious constituents are minerals of the mica family, such as sericite, and not the classically accepted free silica. According to this author,

> The results obtained favor Jones' sericite theory as to the causation of pulmonary silicosis and show how fragile and uncertain is the pathogenic basis for the current conception of pulmonary silicosis.

Collis (170) made the following comment in his abstract of Policard's paper:

> The observations ceased 30 days after dusting, which Kettle has shown to be far too early to determine the "activity" of a dust. Further, the special characteristic of silicosis is its tendency to encourage the growth of tubercle bacilli; it is this which constitutes its noxious nature, not some microscopic reaction. No attention is paid to this matter.

On the other hand, LeClerk (171) reports that of 350 selected underground coal-mine workers carefully examined by physical, X-ray, and clinical laboratory methods 271 were negative, 20 showed discrete benign fibrosis not associated with occupation, 15 had lesions of noninfective pulmonary fibrosis undoubtedly due to anthracosilicosis but with no associated incapacitation, 18 had clinical and radiographical signs of silicosis with slight incapacitation, and 26 had traces of infective pulmonary sclerosis. In this group 13 were definitely silicotic; 8 had definite signs or were strongly suspected of having tuberculosis, and 5 had silicosis with tuberculosis. These cases developed among miners working in a coal-bearing stratum paralleled by strata of sandstone and schist, both of which contain free silica. The fibrous silicate, sericite, does not occur in this region. Of 177 samples of mine dust examined 93 showed crystalline silica in varying amounts (10 to 60 percent).

In his report of a study of silicosis in the granite and foundry industries of Massachusetts Pope (172) states that petrographic analysis showed sericite in significant amounts in the granite from only one city studied - Fitchburg - where the incidence of silicosis was low. In the granite from Milford, where the incidence of silicosis was more than three times as great, barely a trace of sericite was found.

Particle size of dangerous dust.- The significant part played by the size of dust particles is indicated by the fact that although in South Africa visible dust has been very largely removed from the air breathed by the miners silicosis is still produced. Pirow (173) is not convinced that the Rand standard of 300 particles per cubic centimeter is safe. Mavrogordato (174) emphasizes that all visible dust can be easily removed, leaving the dangerous dust; therefore size frequency is of great importance. Naturally the more concentrated the quantity of dust and fume in suspension in the atmosphere the greater the danger to which the workman is exposed, and unquestionably the smaller the particles the greater the likelihood of their entrance into the interstices. The size of particles in prolonged suspension in the air is more likely to be under 5 microns than over; probably the most dangerous dust is that ranging from 2 microns to 0.5 micron or smaller because these impalpable particles readily remain in suspension in the air for long periods of time. The size of fume particles ranges from 1 to 0.2 micron in diameter. In other words, it is thought that the smaller the particles the greater the danger, although there may be a lower limiting size as well as a higher one; unless especially warned, employers and workmen are prone to regard impalpable nonvisible dust as altogether harmless. Dust particles under 5 microns in size readily pass through the mouth and nose, traverse the bronchial passages, and lodge in the alveolar tissue, from which remote parts of the lung structure they usually cannot be dislodged by hawking or coughing. The size of the dangerous dust (supposedly 1 to 5 microns) is roughly that of the tubercle bacillus. Such particles are like smoke or vapor; they cannot be washed down by spray since they recoil from drops of moisture, nor can they be conceived as exerting an abrasive action when moving gently within the lungs. Since similarly fine particles of other dusts when inhaled are not followed by the pathological changes characteristic of silicosis the conclusion (and this is now held by many, probably most,

authorities on the subject) is that silica dust exerts a chemical rather than a physical action upon living tissues. Badham, Rayner, and Broose (175) suggested that if every individual particle is equally dangerous in initiating fibrosis then the 1-micron particle is the worst because it is in the majority; if fibrosis results from chemical action depending on solubility of dust particles then the 2-micron particles are the worst because this size exposes the largest surface; but if the quantity of dust is the most important factor then the 3-micron particle is the worst since this size contributes the most weight. If number, surface, and weight are factors then sizes of 1 to 3 microns are the most pernicious (these authorities apparently are at least somewhat doubtful as to the underlying cause of dust harmfulness). Greenburg (176) considers a knowledge of the weight of dust of much value, but because it is virtually impossible to separate the particles less than 10 microns in size from those over 10 microns to obtain the weight of the injurious particles (those capable of gaining access to the lung tissue) and also because one large particle may weigh many hundreds of times more than a smaller one, the weight of a given sample of dust must be used only as an additional guide in the interpretation of results, and then with some degree of caution.

Quantity of dust required to produce silicosis.- According to Loriga (74), the quantity of dust that will provoke silicosis cannot be given precisely, since it is not the absolute quantity or quality that matters but the relative quantity. One person might resist a proportion of 100 particles per cubic centimeter, while another would react unfavorably to 50 particles; there is also the whole question of the rate of inhalation.

According to Ballantyne (108), in Great Britain the criterion of safety suggested, rather than expressed, in the Workmen's Compensation Schemes goes no farther than the composition of the mineral substance itself. The composition of the dusty atmosphere - that is, the concentration of the SiO_2 therein - is not mentioned; the Refractories Industries Scheme does not apply if the mineral contains less than 80 percent total silica. In the sandstone industry the Scheme ceases to apply if the sandstone is shown to contain less than 50 percent. In the United States (108) it is customary to gage the risk by the number of particles of free silica per cubic foot of air, irrespective of the other constituents of the dust. In South Africa (111) the total number of mineral particles per cubic foot is taken as the basis. Certain standards, chosen more or less empirically from a study of particular industries, have been adopted on these lines. Ballantyne (108) thinks that international agreement on methods of estimating the number of dust particles in the air and of interpreting the "counts" obtained is much to be desired.

Badham (177) states that if the average exposure on the Rand is about 1 mg per cubic meter the prospects of attacking the disease by reducing the amount of dust inhaled seem rather hopeless.

In South Africa, where the dust is said to contain more than 85 percent free silica as quartz, a tentative standard of 300 particles per cubic centimeter of air (8.5 million particles per cubic foot) has been set (178) as the upper limit of dustiness to be regarded as allowable.

Investigation in certain plants of the granite-cutting industry in the United States (178) revealed a content of 31 to 38 percent free silica in the form of quartz. In a study by the Public Health Service (178) the workers were divided into four groups, depending upon the average exposure in terms of amount of dust in the air, with the following results:

> In group A, which included hand-pneumatic tool operators and in which the exposure averaged about 59 million particles per cubic foot of air, it was found that practically 100 percent developed an established silicosis within 10 years from the time of beginning employment. Also, in this group the highest rate was found for cases diagnosed on physical examination as having active tuberculosis. * * *.
>
> In group B were included those workers other than hand-pneumatic tool operators who were also exposed to more than the average plant dustiness. Taking the group as a whole, the average dust concentration was nearly 45 million particles per cubic foot of air. This group showed the same reflection of a dust hazard as group A.
>
> In group C, consisting of those occupational groups exposed to the average plant dustiness (about 20 million particles per cubic foot of air), silicosis developed much more slowly than in the groups just discussed and there appeared to be very little excess in the rate for tuberculosis, with no tendency for an increase according to length of service. Analysis of occupational mortality over a period of 25 years, however, indicated that some of the occupations in this group may have been exposed to a real dust hazard.
>
> Group D was made up of those occupations in which the dustiness was less than that of the average plant atmosphere. The average exposure for the group was less than 10 million particles per cubic feet of air. Although a certain amount of silicosis was found even in this group, there was no indication of serious results, even when the workers had been employed for many years.
>
> From the results of this study it was found practicable to suggest a tentative standard for the upper limit of allowable dustiness between 10 and 20 million particles per cubic foot of air for workers exposed to dust resulting from granite cutting. The same limit would presumably be applicable in the case of other dusts with the same physical characteristics, particularly with a quartz content of about 35 percent.

The Industrial Commission of Wisconsin reports (179) as follows regarding the amount of dust to be allowed in the air breathed by workers:

> The maximum silica-dust concentration considered permissible in the air breathed by a workman at any point in the normal breathing zone has not been definitely established. The commission, its advisory committee, employers and scientists have agreed on a tentative figure of 15 million countable dust particles under 10 microns in longest dimension with free-silica content of 35 percent in a cubic foot of air as

determined by United States Public Health Service technic. Variations in free-silica content will make proportional inverse changes in this standard. In the case of practically pure silica the permissible dust count would be 5,250,000 countable particles. By countable particles is meant those particles within the range of size from 2 to 10 microns in the longest dimension. Dust particles larger than 10 microns in the longest dimension do not ordinarily reach parts of the body where they can produce injury.

From a study made in a bituminous-coal mine the United States Public Health Service (180) found that the incidence rate of respiratory attacks in those exposed to heavy concentrations of dust (105 million particles per cubic foot of air) was 79 percent above that in the group exposed to relatively little dust (3 million particles per cubic foot of air) and 83 percent higher if based on the men employed throughout the period of the study. The excess lies in minor, upper respiratory disease.

Tillson (181) calls attention to the factors affecting the transportation of dusts by the wind as vital to the problem; they are size, shape, and specific gravity of the dust particles and the velocity, density, viscosity, adsorption, wetting power, humidity, temperature, and pressure of the transporting fluid. Various ratios, such as the maximum projected area of surface per units of volume and mass and the total surface area per units of volume and mass, are important derivatives of the particle factors. A thin flake or a needle form (acicular shape) will have a slower settling rate from a horizontal stream than a spherical form of the same volume and mass.

According to Tillson (181), the silica dust found in the lungs has a maximum dimension ranging from less than 0.5 micron to a maximum of about 10 microns (or about 0.0004 inch). Some experts hold that dust less than 0.5 micron in size remains suspended in the expired air and so does not lodge in the lungs, but Tillson doubts whether the evidence is strong enough to warrant such a conclusion. He thinks that too little attention has been given to the form factor of the dust particles in the study and tabulations of dust counts; some observers believe that dusts in the size range 0.5 to 3.5 microns are the most dangerous because of two factors - percentage of surface exposed and percent of volume, respectively, in each intermediate size compared with the total surface of total volume of all sizes from 0.5 to 10 microns when their frequency ratio in the whole amount of such dust is considered. Many persons believe that dust over 5 microns in size is not particularly dangerous.

Tillson says (181) that it is an oversight to consider the dust particles recovered from the lungs by post mortem as evidence of the size and nature of the particles that are most dangerous, because silica dissolved in the slightly alkaline fluids of the body is thought to be responsible for abnormal conditions of the cell structure of the lungs; therefore, the dust that has produced the disease probably has been partly or wholly dissolved and cannot be recovered. Moir (182), of South Africa, found that 13 percent of 126 dust particles from 2 specimens of a silicotic lung were less than 0.5 micron, 36 percent less than 1 micron, and 60 percent 1 to 3 microns, so that the median

size was 1.3 microns. Bloomfield (183) studied 11 different kinds of aerial industrial dusts and found only 2 percent less than 0.5 micron, 21 percent less than 1 micron, 71 percent 1 to 3 microns, and the remainder less than 5 microns. Badham (184), of New South Wales, found that 67 percent of the dust particles smaller than 8 microns examined by him were below 1.5 microns in maximum dimension and that only 1 in every 3,000 was 8 to 10 microns or greater. The authorities at Broken Hill, New South Wales, found that for every particle, in a count of 3,500 particles in lung sections, having a diameter greater than 7.5 microns at least 100,000 particles of a smaller diameter were present; but McCrae (185), of South Africa, found that 70 percent of the quartz particles in the ash of silicotic lungs was less than 1 micron in size. Premised on the number of particles of silica dust per cubic centimeter of air (specific gravity of silica, 2.64), Badham (184) has computed that the respective amounts, depending on shape of particle, will add 1 mg of weight to 1 cubic meter of air: Tetrahedral particles (triangular pyramids), 400 per milligram; spherical particles, 90 per milligram; and cubical particles, 50 per milligram. At an average figure of size-frequency ratio of 3 to 1 he assumes 100 particles per milligram, of which 87 percent by weight are smaller than 5.5 microns. He states that the size-frequency ratio will vary with the time allowed for settling before the sample is taken. In South Africa investigators found that 20 minutes were required for 5-micron particles to settle 6 feet in quiet air and that 8 hours were required for a 1-micron particle to settle the same distance. Jones (186) noted that the granular silica particles settled more rapidly than the smaller acicular sericite particles, so that the percentage of silica dust in the air after blasting was almost invariably lower than in rock borings, noticeably so when samples were taken 3 hours after blasting. He also calls attention to the fact that a 10- by 8- by 5-micron quartz particle taken from a lung has a volume equal to 800 sericite fibers 2 microns by 0.5 micron wide and deep and that the quartz grain has 1,630 times as much silica as the sericite fibers. He does not suggest that no quartz enters the alveoli of the lungs but that he has found scores of sericite fibers there for every grain of quartz.

Jones (186) also states that he extracted 10 grams of dust from the lungs of a man who died from silicosis after 14 years' exposure. Therefore, if the unknown amount of dust which the lungs ejected or dissolved is ignored, the accumulation amounted to 0.0024 gram (240 million particles) per day. He assumes that less than 1/400 gram (250 million particles) per day produces fatal silicosis and states that he has known of other lungs in which the dust proved fatal with only 1/1200 gram (83,300,000 particles) per day. In the former case Tillson (181) assumes from Badham's figures that there were only 1 million million particles in the lungs. The United States Public Health Service has recommended a dust content below 10,000,000 particles per cubic foot of air in granitework where the quartz content of the rock is 35 percent and affirms that 6,000,000 particles per cubic foot of air is the acceptable limit where sand-blasting is done with quartz sand (90 percent or greater content). If the amount of lung ventilation during violent exercise is accepted as 42 to 43 liters per minute according to Tillson (181) about 1.5 cubic feet of air per minute are apparently inspired, therefore the concentration of dust noted above would supply more silica dust in 3 to 3.25 years than has been found as the lethal content left in the lungs. Some writers

claim, however, that only 50 percent of the inhaled dust remains trapped in the lungs and nasal or respiratory passages, the remainder being exhaled. If the air in the streets of lower Manhattan, New York City, the dust count of which is 3.2 million per cubic foot of air, were entirely siliceous, according to Tillson's calculation about 4 years' exposure might supply the 10 grams cited by Jones, and on the basis of 50 percent elimination 8 years would provide a lethal dose. As cited by Bloomfield (183), dust counts for different occupations of the granite-quarrying and granite-finishing industry ranged from 17 to 144 million particles per cubic foot with a quartz content of 35 percent; in quartz-grinding plants the counts ranged from 55 to 173 million particles per cubic foot with a 99-percent quartz content. Death, then, would be expected after exposure for 54 days. Evidently the human system has more effective ways of disposing of such dust, considerable time is necessary to produce the fatal toxic and pathological changes, or possibly (as Jones suggests) the free silica is not the important dust hazard, but some other mineral present in minute percentages is chiefly injurious.

Watkins-Pitchford (187) has stated that experimental observations on animals show that if exposure to silica dust is intense enough no individual will escape development of nodular pulmonary fibrosis. If the quantity of dust inhaled by miners has been relatively small it may be surmised that the processes whereby the particles are removed from the lungs generally are active enough to prevent that degree of accumulation of particles prerequisite to the development of the ordinary form of silicosis. However, he calls attention to the fact that despite the nondevelopment of silicosis in some of those exposed to dust for a long period it appears that many of them nevertheless are faced with the liability to such development. As an example, he states that several of the long-service miners who took part in the World War and who were nonsilicotic when they left their work had developed the disease when they returned. He considers that this state of liability depends upon the continued retention in the lung tissues of the requisite number of silica particles; it ceases when a certain proportion of them have escaped in the expectoration, have been removed by other channels, or have dissolved finally. The agency which converts the liability into a manifestation of the disease in any particular case is usually a tuberculous infection. The state of the individual thus liable to develop the disease without inhaling any more silica dust is conveniently referred to as latent silicosis.

Length of dust exposure required to produce silicosis.- A significant point mentioned in a medical report by Sutherland and Bryson (188) on the incidence of silicosis in the pottery industry, published in 1926, was the frequency with which fibrosis of the lungs was diagnosed by medical examination at a period of employment earlier than that at which silicosis had been found by radiological examination in the same occupational groups. The report states that possibly fibrosis of the lungs, as found clinically, develops in a shorter time or requires a lower concentration of dust than silicosis discernible radiologically; therefore, in occupations where both conditions are found fibrosis of the lungs commonly precedes silicosis. The cases of silicosis in the pottery industry, grouped in the report according to years of employment, were:

Years	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	Over 40
Cases	1	2	8	7	14	15	15	8	17

According to this table, most of the cases in the pottery industry develop after 20 years of employment in the industry. The authors consider it significant that in the occupations where the incidence of silicosis is high the disease becomes evident at an early stage in the occupational history (188).

The period of exposure required to produce silicosis depends primarily on the individual, according to Moore (189). In the Bendigo mines the silica content of the dust is over 90 percent; on the west coast of Tasmania, about 60 percent; and in Kalgoorlie, a little above 60 percent. Moore (189) states that the Bendigo statistics are not very trustworthy, as the miners are loth to be examined, but the average period required to produce silicosis seems to be about 10 years; in Kalgoorlie it is nearer 16 years. He concludes that silicosis seems to depend pretty accurately on the silica average in the country rock.

Böhme (190) cites German experience to show that sand-blasters and sand-grinders have well-developed silicosis sometimes after 3 years' exposure; generally it develops after about 10 years. Koelsch (191) observed that 2 cases of severe silicosis developed after 2.5 years of employment on sand-blasting; the workers were 25 and 30 years old, respectively.

According to Cunningham (192), the exposure necessary to produce ante-primary silicosis in Ontario gold mines is 9 to 10 years. The percentage of free silica is about 30 to 35. In England the apparent exposure to silica dust necessary to produce silicosis has been short; Middleton (193) mentions a case of fatal tuberculosis with evidence that it had been produced by silicosis after 2.5 years of exposure.

More investigative work on silicosis has been done in South Africa than in any other country; the following summary of experience in that country on this phase of the subject is therefore interesting (194):

> In previous reports one has had occasion to emphasize the fact that the data regarding the mean duration of service of new silicotics obviously apply only to those miners who do actually contract the disease. They cannot be taken as a measure of the "average effective life of a miner" in the sense that all working miners will on the average become silicotic after some 14 years of underground work, since they leave out of account the service of the remaining miners who have not contracted the disease, and some of whom may never do so.
>
> On the rates of incidence of the compensable diseases which obtained in 1918 to 1920, 50 percent of the original

body would have become affected by one or other of these diseases by the 13th year of work; on the rates of 1920 to 1923 the corresponding figure would have been the 17th year; on those of 1928 to 1929 the 20th year; while, from the trend of the figures calculated on the incidence rates obtaining in 1931 to 1932, it can be concluded that a corresponding position would not be reached now until between the 25th and 26th years of underground work. This method of analysis affords a concrete illustration of the progressive potential advantage conferred by the progressive fall in the rates of liability to contract silicosis to which reference has repeatedly been made.

The effect of long exposure to granite dust is shown in the history of 8 cases cited by McFarland (195). In 3 cases of simple silicosis the ages were 34, 39, and 42, while the duration of exposure was 14 years in the first case and 23 in the other 2. In 5 cases of silicosis with tuberculosis the ages were 50, 56, 57, 59, and 63, and the years of exposure 35, 42, 34, 38, and 50, respectively.

In a study of sandstone-quarry workers Hayhurst and his co-workers (196) found that the stage of silicosis varied in proportion to the years of exposure except that silicosis plus tuberculosis manifested itself as early as beginning silicosis, that is, after about 15 years' exposure; they found that few men suffered from silicosis under 25 years of age but that at 34 there were as many silicotics as nonsilicotics and again after 44 years of age there were sometimes more silicotics than nonsilicotics.

In an investigation of the granite industry the United States Public Health Service (99) found that in the group of workers exposed to the heaviest dust the first case of silicosis appeared after approximately 2 years and by 4 years all in this group seemed to have developed at least an early case of silicosis. In the same group the first case of more developed silicosis appeared after 5 years of service, and by 9 years approximately 90 percent had advanced to this stage. In the group with an average exposure of less than 10 million particles per cubic foot of air 2 cases of early silicosis had developed after 10 years' exposure and 1 case of moderate silicosis after 6 years.

In a similar study of the cement industry the Public Health Service (103) found that the earliest case of pneumoconiosis appeared after 3 years' exposure to cement. Of 53 men selected for examination 37 had worked in the industry more than 3 years. Of the 37, 15 showed evidence of pneumoconiosis, and 3 of these also had tuberculosis; of 22 who showed no indication of pneumoconiosis 8 gave evidence of arrested tuberculosis, 4 showed no evidence of either pneumoconiosis or tuberculosis, and 10 were considered doubtful.

Chapman (197) reported three cases of acute silicosis, among the first cases in American industry, in which the appearance of respiratory symptoms after 8, 21, and 29 months of exposure to an alkaline dust of high silica content marked a more rapid and severe silicosis than usual. He states that the rapidity of the process, in contrast to the usual chronic form, probably was due to the accelerated formation of silica hydrosol in the presence of an alkaline soap dust. MacDonald (198) described the rapidly fatal cases of 2

young girls who had been employed 2.75 and 4.25 years packing a silica soap powder. According to Chapman, Russell (199) saw the disease fully developed in a lens grinder who inhaled a pure quartz spray for 8 months.

In describing four cases of silicosis or silicosis and tuberculosis which developed many years after relatively short exposures Britton and Head (200) stated that cases of this kind suggest the necessity of revising the conception of the length of exposure necessary to produce the disease and emphasize that once a man has developed symptoms while still engaged in the dusty occupation stopping the work does not prevent the gradual, steady progression of the pathologic changes. The cases described developed symptoms of silicosis 23 years after an exposure of 4 months, 10 years after an exposure of 2 years, 14 years after an exposure of 4 years, and 10 years after an exposure of 10 years. The following table taken from the Colliery Guardian (201) gives the number of deaths from silicosis and silicosis with tuberculosis, by industry, average age at death, and duration of employment reported for 1932 to the British Factory Inspection Service:

Industry	Number of deaths	Average age at death	Duration of employment, years		
			Longest	Shortest	Average
Pottery:					
Silicosis..................	72	55.6	57.0	10.0	39.8
Silicosis with tuberculosis	75	55.2	67.0	13.0	37.9
Sandstone:					
Silicosis..................	21	57.3	57.0	20.0	40.4
Silicosis with tuberculosis	39	52.3	55.0	16.0	34.8
Grinding of metals:					
Silicosis..................	4	47.3	45.0	18.0	30.8
Silicosis with tuberculosis	26	51.1	48.0	2.8	30.2
Sand-blasting:					
Silicosis..................	7	40.7	13.0	4.5	10.3
Silicosis with tuberculosis	16	44.2	20.0	2.5	8.3
Scouring-powder manufacture:					
Silicosis..................	3	37.0	11.0	5.25	7.8
Silicosis with tuberculosis	2	33.5	10.75	2.0	6.4
Miscellaneous:					
Silicosis..................	7	55.3	45.0	2.8	20.4
Silicosis with tuberculosis	9	50.9	34.0	11.0	24.0

The diagnosis of all these cases was verified by post-mortem examination.

Kilgore (202) shows the course of six cases of pneumoconiosis developed after comparatively short exposures to pulverized quartz used in a polishing powder:

Case	Age, years	Dust exposure, months	Onset after exposure, months	Life after exposure, months
1	70	16 (not grinding quartz)	(?)	84
2	50	27	(?)	23
3	36	14	14	Still living
4	39	14	24	50
5	31	10	9	14
6	31	12	11	21

In a study (90) of the effects of exposure to dust in coal mining the Public Health Service found an apparent relation between the occurrence of generalized fibrosis and length of time the workers had been employed in the industry. The percentage rises from 4.8 in the group with less than 5 years' service to 69 in the group with more than 15 years' service; even if attention is confined to workers under 45 years of age, the percentage in the group with more than 15 years' service is 66.7.

Pancoast and Pendergrass (22) found that the longest period of occupation in a sand-pulverizing plant was 2.5 years at intervals , and the shortest was said to have been only 35 days during a period of a little over 1 year before symptoms of lung affection appeared.

Quaintance and Morris (203) examined 58 pottery workers in an industrial plant manufacturing bathroom ware, using a silica content of approximately 25 percent. After an average exposure of 16 years 8.6 percent of these workers had advanced fibrosis; 38 percent had second-stage or moderate fibrosis, and 63.5 percent had only slight fibrosis.

Data collected by the United States Bureau of Mines (89) at Picher, Okla., show that first-stage silicotics had worked underground 2 to 30 years, an average of 12.99 years for all men, irrespective of occupation; for facemen, 12.34 years; and for men exposed to large amounts of dust, such as drillers, shovelers, and their helpers, 9.6 years. Second-stage silicotics had worked underground 2 to 36 years, an average of 15.8 years for all men, irrespective of occupation; for facemen only, 13.3 years; and for drillers, shovelers, and their helpers, 12.8 years. Third-stage silicotics had worked underground 3 to 40 years, an average of 18 years for all occupations; for facemen only, 16.1 years; and for shovelers, drillers, and their helpers, 15.5 years. The average number of years worked before the various stages of silicosis developed is shown in the following table (92):

	Years
First-stage silicosis	11.9
Second-stage silicosis	14.3
Third-stage silicosis	17.1
First-stage silicosis plus tuberculosis	19.4
Second-stage silicosis plus tuberculosis	18.0

	Years
Third-stage silicosis plus tuberculosis (only 2 cases)..	11.5
Early tuberculosis..................................	8.7
Moderately advanced tuberculosis......................	21.2
Advanced tuberculosis (only 1 case)...................	30.0

Examination of ex-coal miners failed to reveal any benefit from previous exposure to coal dust. Of the 599 ex-coal miners who had worked in coal mines for periods ranging from a few weeks to 52 years (average, 12 years) 167 had silicosis in 1 of the 3 stages. The periods that these coal miners worked in zinc and lead mines averaged 7.7 years for first-stage silicotics, 9.0 years for second-stage silicotics, and 14.9 years for third-stage silicotics

Lochtkemper and Teleky (66) found that silicosis developed after 2 years' work in a polishing-powder factory and in sand-blasting with the free blast, both occupations showing the highest number of dust particles; in automatic sand-blasting rooms with only 160 dust particles per cubic centimeter silicosis did not develop until after 4 or 5 years' exposure. An early case of silicosis developed in the crushing mills after 3 months' work, stage II after 1.75 years, and stage III after 2.75 years. Stage III silicosis developed after 6 and 15 years' exposure in cementworks, where the greatest number of particles were quartz sand; when the quartz dust was mixed with clay dust stage III silicosis was reached sooner.

Dreessen (204), in his study of the effects of silicate dusts, found pulmonary fibrosis or pneumoconiosis in all 6 workers who had been exposed for 6 years or more to 1,440 million particles per cubic foot of tremolite talc. Of 33 workers exposed to 53 million particles per cubic foot 10 showed signs of pneumoconiosis, 1 after 5 years 1 after 6 years, 2 after 9 years, 1 each after 11 and 12 years, 1 after 15 years, and 2 after 30 years or more of exposure; 1 man who had worked in talc for over 40 years had second-stage pneumoconiosis. In the group exposed to 4 million particles per cubic foot no definite cases of pneumoconiosis were observed.

From a study of granite cutters in New York City Smith (205) reports the following regarding length of exposure to dust and development of silicosis:

> The average age in the negative group was 30 years. In the "increased-fibrosis", "questionable-silicosis", and "first-stage-silicosis" groups it ranged in the vicinity of 41 years; in the group showing second-stage silicosis it was 57, and in the group with evidence of tuberculosis and silicosis it was 50 years.
>
> Three of the men examined had been exposed under 5 years; these cases fell in the "negative" and "increased-fibrosis" groups. Three had been exposed over 50 years; these cases fell in the "second-stage" and "tuberculosis-with-silicosis" groups. Among the cases showing first-stage silicosis, more fell in the 20- to 29-year exposure group than any other, though 2 had been exposed less than 10 years. Among the cases with second-stage

silicosis more fell in the 30- to 39-year exposure group than in any other. Among those with silicosis and tuberculosis the majority had been exposed from 20 to 39 years. The cases showing "questionable silicosis" were equally distributed over all exposure groups from 5 to 39 years.

The picture given is one of a slowly developing type of silicosis which may show its first stages after anywhere between 5 and 40 years and tends to become advanced with a marked tendency to be complicated with tuberculosis after 20 years' exposure.

The following statement from the Colliery Guardian, August 10, 1934 (206), gives additional data on the length of exposure required to produce silicosis and the average age at death:

> Full particulars are available of 469 deaths from silicosis or silicosis with tuberculosis, in which there is no doubt as to the precise cause of death. In the 204 deaths from silicosis the average age at death was 54.3, and the average employment 34.3 years (2.3-60 years), whilst in the 265 deaths from silicosis with tuberculosis, the average age at death was 52.3 and the average duration of employment 31.5 years (2-67 years).

The relation of the amount of dust breathed and length of exposure to the development of silicosis is shown by the investigations of Bloomfield and Dreessen (207) in a granite quarry and by Pope (172) in the granite and foundry industries. Bloomfield and Dreessen (206) found that in the quarry industry pathological changes due to dust are limited to drillers--the only persons creating dust. The Leyner drillers and plug and jackhammer drillers working in the quarry holes were exposed to 144.4 and 112.1 million particles per cubic foot. Ten drillers showed signs of silicosis, half of those exposed 5 to 19 years had silicosis, and 4 of the 5 men exposed for more than 20 years were affected.

The following table prepared from Pope's report (172) shows the relation of amount of dust breathed and length of exposure to production of silicosis in the granite and foundry industries:

Dust Count	Weighted average of median dust counts, Million particles per cubic foot		Percentage having silicosis					
			Under 10 years		10 to 24 years		25 years or [illegible]	
	Foundry	Granite	Foundry	Granite	Foundry	Granite	Foundry	Granite
Group A	32	40.4	5.1	4.8	20.6	31.9	43.7	62.8
Group B	14	17.1	4.6	4.6	12.1	10.8	34.3	20.8
Group C	5	8.9	.7	6.0	5.6	11.1	25.9	6.3

Section 2. - Determination of Dust in Air

The recognition of inhaled dust as the main factor in the production of pulmonary disease among miners drew attention to the quantitative aspects of the problem and the importance, as regards health, of determining the amount, weight, and particle-size frequency of the dust in air breathed by workers in various industries--especially those known as "dusty." Determination of dust also is becoming increasingly significant economically as evidence of the extent of the dust hazard involved in various dusty processes and as a measure of the efficiency of protective devices introduced to mitigate the hazard.

Determination of the dust content of the air by any of the more generally used methods entails the two processes of sampling and measuring the quantity of dust in the sample. Mavrogordato (208) classed the methods according to the nature of the sampling process--whether by precipitation (the konimetric or optical method) or by filtration (the sugar-tube or gravimetric method). Green (20_) refers to two main types of methods used for sampling dusts: (1) Methods by which bulk samples of the dust are extracted from the air for weighing and chemical analysis, for example, the sugar-tube method; and (2) methods by which dusts are collected in a state suitable for microscopic examination, for example, the konimeter. After the sample has been collected the particles are counted, and/or the mass is weighed (209).

The ideal instrument (176) must be capable of efficiently sampling the dusty atmosphere with particular reference to particles ranging from 0.5 micro to 10 microns, and it should be possible, once this sample is obtained, to count the number of such small particles present; from the hygienic viewpoint the count is the best index of the extent of atmospheric pollution. Determination of the weight of the dust would also be valuable; but because it is virtually impossible to separate the particles under 10 microns in size from those over 10 microns and thus obtain the weight of the injurious particles (those capable of gaining access to lung tissue) and because one large particl may weigh many hundreds of times more than a smaller one, the weight of a give sample of dust should be used only as an additional guide in the interpretatic of results, and then with some degree of caution.

The range in dust concentration over which determinations might be required is very great. Some atmospheres (those prevailing outdoors after rain storms) contain very small quantities of dust, whereas the air of mines or abrasive factories often is highly polluted; therefore, the instrument must be capable of sampling both high and low dust concentrations with equal efficienc an exacting requirement, as it means that the dust-collecting medium (whether water, sugar, or an adhesive) must not add greatly to the dust of the sampled air. The "control" or "blank" of the instrument must be low, and it must be uniform in dust content; in other words, a sample of the collecting medium must be so uniform that the analysis of a representative sample gives a true picture of the dust content of all of it used in a given series of tests.

As the dust concentration of air is changing continually, the instrument must be capable of sampling large quantities of air (176) to obtain a true picture of the condition. Once the sample has been obtained, the analysis

should be as simple and rapid as possible; the more time-consuming and complex the method of analysis the lower its value. In many mines of the United States no electric power is available, and an instrument used for mine-dust sampling must be hand-driven; the instrument must be lightinweight and portable and of a size to permit introduction into a working place without interfering with the workers' movements.

To summarize, the final choice of an instrument for sampling dust depends on its efficiency, its small errors in analysis, its portability and weight, and on the difficulty or ease with which the samples obtained may be analyzed. The instrument or method should also be able to eliminate, as far as possible, variations or errors due to the "human equation"--a difficult requirement.

Dust-Sampling Methods

In general, dust-sampling methods can be grouped according to the physical principle utilized by the sampling instrument (176). This cannot be an exact classification because some instruments involve the use of more than one physical principle. The chief methods used for sampling aerial dust are: Condensation, filtration, washing, sedimentation, electrostatic, resistance, and impinging. Greenburg (176) gives the following historical summary of the various methods.

Condensation

In 1875 Coulier (210) showed that dust in air could be made visible by reducing the pressure within the containing vessel, causing the moisture in the air of the vessel to condense on the dust particles. He further showed that condensation might be prevented by filtration of the air through a layer of cotton wool. This principle has since been utilized by various investigators.

Aitken koniscope.--The Aitken koniscope, described by John Aitken in 1889 (211), consists of a metal tube and suction pump placed at right angles and joined by a connecting post. The metal tube, lined with hygroscopic material, is provided with a window at each end and a stopcock at the end distal to the point at which the pump is attached.

In operation the tube is held horizontally and the pump vertically, the observer looking through the window in the tube at the point of attachment with the pump. Air is drawn into the apparatus by means of the pump, and the stopcock is then closed. The air, more or less saturated with moisture from the hygroscopic material in the tube, is rarefied by depressing the pump once again. The dew point is thus lowered, with the formation of a fog or cloud due to condensation of the moisture on the dust present. The density of the cloud or fog is then compared with suitable standards and a qualitative estimate of the air dustiness established.

Aitken dust counter.--An improvement on the koniscope was devised by Aitken (212); this essentially makes use of the same principle as the koniscope, but an attempt is made to count the number of particles in the air. In its earlier form the instrument was large and nonportable. It consisted of a re-

ceiver, an air pump, an air-measuring device, an illuminometer, and a gasometer. The air was drawn into the receiver by the gasometer. As it entered the receiver it was measured and mixed with a known quantity of dust-free air, saturated with water, and then rarefied by the pump. The rain, produced by condensation of water on the dust present, fell on the ruled, polished silver plate that formed the bottom of the receiver. The number of droplets on the counting plate multiplied by the proper factors for the amount of air sampled and the dilution with dust-free air gave a count of the number of particles present in the original sample. In addition to the disadvantage of being very large and nonportable manipulation is rather intricate and liable to large experimental and personal error.

Modified form of Aitken dust counter.--The modified Aitken dust counter, devised to overcome some of the drawbacks of the earlier instrument, consists of a hollow box with a ruled glass bottom and a plain glass top and is supported on two cylinders which open into it (213). One of the cylinders forms an air pump and contains the piston; the other cylinder is provided with three taps (stopcocks), the bores of which are of known volume. A plug of cotton wool is placed in the cylinder below the three taps, and the lower end of the cylinder is perforated so that air may enter. A mirror is supported beneath the receiver, and above it is a magnifying lens. Strips of damp blotting paper within the receiver saturate the air with moisture. By drawing down the piston when the stopcocks communicate with the cotton-wool chamber filtered air is drawn into the receiver. One of the taps (depending on the dustiness of the air to be sampled) is then turned at right angles to communicate with the outside air; it is then turned back again and the piston drawn down, bringing the sample of dusty air properly diluted with dust-free air into the receiver, where the dust is precipitated with the moisture in droplets on the ruled glass plate and the drops counted. Multiplication of the count by appropriate factors, as the volume of air sampled, gives a final figure for the number of particles of dust present in the original sample. This instrument is portable, being arranged on a tripod for field use. It has the disadvantage that the amount of air sampled is very small, and the opportunities for personal and experimental error are many. The most serious drawback is that all particles of dust receive equal significance, irrespective of size, since this method takes account of particles of ultramicroscopic size.

Hill diffractoscope.--The Hill diffractoscope (214) is essentially the same as the Aitken koniscope. The results are only qualitative, giving a rough estimate of the dust present by observation of the intensity of a beam of light directed into the window of the rarefied air chamber (Tyndall effect).

Jet dust-counting apparatus.--An adaptation of the principle of condensation is utilized in Owens' device (215), which he describes as follows:

> A high-velocity jet of air is caused to strike a microscope cover glass; the effect of this high velocity is to bring about a fall of pressure in the jet, accompanying which, and resulting from it, is a corresponding fall of temperature. This in turn causes a condensation of the moisture in the air upon the dust

particles, which are thus projected wet against the cover glass, and, as the water evaporates, are left behind adhering to the glass.

In this apparatus the air is moistened by being passed through a chamber lined with moist blotting paper and is then drawn at high velocity through a slot about 1 cm long and 0.1 mm wide. After passing through this slot the air loses heat, and the moisture present condenses on the dust particles left on the microscope coverslip, forming the top of the cells. The coverslip is then placed under the microscope, and the particles are counted.

In his summary of the value from the viewpoint of industrial hygiene of the instruments designed to utilize the principle of condensation of moisture on dust particles Greenburg (176) states that those which permit a qualitative estimate only of the quantity of dust present have little practical value; those which permit the particles to be counted give results of limited significance because of errors in sampling and analysis and because of the difficulty of interpreting the counts, owing to the grouping of particles of ultramicroscopic size (which do not so far as is known constitute a health hazard) with those of a significant size from the hygienic viewpoint. The Owens apparatus yields high counts in normal indoor air; in very dusty atmosphere, however, the ribbon of dust on the microscope coverslip is so dense that counting the particles, even at high magnification, is difficult and often impossible.

Fehnel (216) mentions the following objections to the Owens jet dust counter:

1. The volume of sample, to be a fair, representative average, should be taken over a period of time because, except in a very few instances, the generation of dust is an intermittent process and is not constant.

2. The ribbon in the Owens jet counter sample does not have definite boundaries, and therefore counting the particles in a representative average band or integral part of the whole ribbon is very difficult.

3. The rate and efficiency of sampling with the Owens jet dust counter depend upon how rapidly the operator actuates the plunger. Also the washers are troublesome, and it is difficult to maintain the piston free of leakage.

4. It has been demonstrated that the Owens instrument is selective, sampling only particles of 6 microns and under.

Filtration

The principle of filtration has been applied to dust sampling in such various forms that only a few of these methods (176) need to be mentioned. In general, the air is filtered through cotton wool, cloth, paper, or a soluble chemical compound and the analysis made either by comparison with qualitative standards, by weighing, by counting the dust particles, and in some cases by both weighing and counting the dust.

Cotton-wool method.--This method has been used by Arens, Cohen, Harcourt, Duckering, Cohen and Ruston, and Ditman (176). It yields only the weight of the dust in the air, and although it is a very valuable method for the estimation of toxic dusts (lead or arsenic) it is of limited value in determining the potentiality of a dust as a producer of pneumoconiosis.

Cloth method.--This involves the principle of filtration but utilizes cloth instead of cotton wool. Stacy (217) used cheesecloth squares, which were weighed before and after the dust was sampled; the difference was considered the weight of the dust caught. Hill (218) used weighed cloth filter bags placed in a conical metal holder and connected to an anemometer for measuring the volume of air sampled. The difference in weight before and after sampling was considered to represent the amount of dust in the quantity of air filtered. This method was cumbersome and inaccurate and required too much time for a single determination. An apparatus similar in principle is known as the American automatic dust filter (219); the air is filtered through a series of four or more specially woven cloth bags in a closed cabinet. The difference in the weight of bags before and after passage of the air is taken as the weight of the dust in the volume of air passed through the instrument. The deficiencies of this instrument are similar to those of the Hill bag method previously described. The Carrier dry-filter apparatus (220) attempts to keep the filter bags dry during the sampling period by heating the air with an electric heating unit before it passes into the filtration bags. Because of the high temperature involved Todd (221) utilized disks of Canton flannel, held in a special device. The air was filtered through the cloth, which retained the dust; the disk then was compared with a series of standard disks ranging from 1° to 10° of a rather arbitrary scale. With some of these methods it is possible to graduate or classify roughly various atmospheres in groups based on the amount of dust present; but even then Greenburg says (176) serious error from the hygienic standpoint is involved, for an atmosphere of many small particles (small enough to gain access to the lung tissue and hence injurious) may give a lower scale reading than an atmosphere containing a smaller number of particles of relatively less hygienic significance.

The Gooch crucible (176) has been used with some success; this apparatus usually is an ordinary porcelain or platinum Gooch crucible, the bottom of which is covered with a mat of shredded, acid-treated asbestos. The crucible is dried and weighed carefully, placed in a suitable holding device, and a known quantity of air drawn over it, after which it is again dried and weighed. The difference in weight is taken to represent the weight of the dust in the quantity of air sampled. The filtration surface is small, and if the mat is thick enough to retain the greater portion of the dust the resistance to air flow is very high, and therefore only a small quantity of air can be sampled.

Filter paper.--To overcome the objections to cloth filters and the Gooch crucible recourse has been had to filter paper for sampling dust. One of the earliest methods for the determination of dust by a filtration process was that of Rubner (176); a holder in which was placed a piece of filter paper was connected by suitable tubing to a water-jet pump. The volume of air drawn through the paper was measured by a gas meter in series with the pump and paper holder. The dust was estimated by comparing the filter paper with

a standard scale. Filter paper has been used by Sargent (222), Moller (223), Hubendick (224), Johannsen (225), and Nesbitt (226). This method was used in Great Britain in studies conducted by the Advisory Committee on Atmospheric Pollution in 1916-17. An automatic apparatus was built by which 3 or 4 samples were taken each hour.

Paper thimbles.--Filter-paper thimbles have been used successfully in a number of dust investigations (173). The apparatus consists of a filter-paper thimble (similar to a Soxhlet thimble) and its holding device, by which the air is drawn through the thimble, and a meter for measuring the air. The thimble is dried in an oven and weighed before and after filtration, the difference in weight being taken as the amount of dust in the air sampled. Various grades of filter paper may range in efficiency from 63 to 90 percent when tested optically, using tobacco smoke as the test dust. The chief drawback from the hygienic viewpoint is that particles cannot be counted by the use of filter paper or filter-paper thimbles. Moreover, the utmost caution must be exercised in drying and handling the filter paper to avoid absorption of moisture and resulting errors in weighing. In an effort to overcome these objections many workers (179) have used another type of filtration method in which the air is filtered through a soluble chemical compound. After being sampled the substance is dissolved, and the amount of dust is determined both by weight and by count or by comparison with a scale of standards.

By Hahn's method (227) air is drawn through a filter of collodion wool and the quantity measured by piston displacement. After a suitable amount of air has been sampled the collodion is dissolved in ether, and the solution is then compared with a series of arbitrary standards.

The most successful method of this type, one utilizing granulated sugar to filter dust, was first employed by Frankland (228) and later by various others, including the Miners' Phthisis Prevention Committee of South Africa (229), Higgins, Lanza, Laney, and Rice (230), and Fieldner, Katz, and Longfellow (231). This method employs a sampling tube, in which a weighed amount (100 grams in the later types) of clean granulated sugar is placed. The dusty air is drawn through the tube by a pump or other suitable device. After a sufficient quantity of air has been sampled (usually 15 cubic feet) the sugar tube is taken to the laboratory for analysis. The sugar is dissolved in hot water, and count and weight determinations are made on the dust present.

Fieldner and his coworkers (231) found the efficiency of the sugar tube to be approximately 35 percent when it was tested optically with tobacco smoke and about 87 percent when tested gravimetrically with silica dust. These results would indicate relatively high filtering efficiency. Both weight and count of the number of insoluble and noncombustible dust particles present in a given atmosphere are obtained by this method. It has the disadvantage that a large and variable quantity of dust is present originally in all samples of sugar; it therefore cannot be used effectively for sampling either soluble or inflammable (combustible) dust.

Washing

Washing methods have been applied to the sampling of insoluble dust with much success (176). These methods, in general, bubble the dust-laden air

through water to the dust and bring it into suspension. The amount of dust present may be estimated by weight and count.

Palmer dust apparatus.--This apparatus was devised in 1916 (232). It is a pear shaped glass bulb, at the base of which is a water trap so arranged that the air is drawn through the trap (preferably at a rate of 4 or 5 c. f. m.) and breaks the water into spray which washes the dust from the air. After a suitable quantity of air has been sampled, depending on its dustiness, the water is drained from the trap and taken to the laboratory for analysis. By this method both weight and count determinations may be made of some kinds of dust.

Variations of the washing methods have been devised by Meyer (233), Read (176), and Drinker (234). The main difficulty with washing methods, according to Greenburg (176), lies in the inability to wet very small particles of dust in the brief interval requisite to sampling large volumes of air. One obvious advantage of this method over the sugar-tube method is that the water used, if properly distilled, contains little or no dust, while the sugar in the sugar tube method, no matter how carefully prepared, always contains a large and variable quantity of solids.

Sedimentation.

In 1879 Miquel (235) described a method of collecting dust by allowing it to settle on plates. The particles were counted under a microscope. In 1880 Tissandier (236) substituted sheets of paper 2 meters square for the glass of Miquel. The paper was supported horizontally, and after a suitable time the dust was collected by a small brush and examined under the microscope. In 1902 Irwin (237) estimated the dust in Manchester air by collecting a volume of snow 100 square inches in area and 1 inch in depth. The snow was melted and filtered and the residue dried and weighed. Liefman (238) utilized two oil-coated disks on a revolving vertical shaft, one supported horizontally and the other vertically. A vane keeps the vertical disk facing the wind; this disk collects some dust by impaction, while the horizontal disk collects the dust deposited by sedimentation. The dust laden oil is removed from the plates by ether, and after evaporation the dust is again suspended in 5 cc of oil. The final suspension is compared with a series of standards made by mixing various quantities of soot and oil. This method allows only a rough quantitative estimate of the dust present in the atmosphere.

Des Voeuz and Owens (239) used an enameled iron vessel 2 square feet in area arranged somewhat like a large funnel. The dust was washed down into a bottle beneath the funnel by rain. The Advisory Committee on Atmospheric Pollution of the Meteorological Office of Great Britain also used this method. Hill (218) used porcelain evaporating dishes; Mitchell (240), rectangular glass plates coated with vaseline and placed on poles 25 or 30 feet above the street level; and Whipple (241), 2-quart tin pails coated inside and out with resistant varnish and suspended on poles about 20 feet above the street level. This method does not sample the air but permits an estimate of the quantity of dust that settles on the surface of the water.

Gravity settling methods, in general, do not indicate just how much dust a given sample of air contains but aid in estimating the amount of dust falling on and adhering to a given surface, either oiled, wetted, or dry, in a given period.

Green (242) describes accurate sedimentation methods for determining the number and size-frequency of particles in dust clouds. The containing vessel for the sedimentation cell is a brass cylinder 5 cm deep, and 3.6 cm in diameter; it can be closed at the top by a swivel lid and at the bottom by a brass slide in which two $\frac{1}{2}$-inch coverslips are mounted, thus enabling a known volume of cloud to be trapped in an airtight space. The coverslips are slipped into holes in the underside of the slide and lie almost flush with its upper surface, being pressed firmly against a narrow rim at the top by means of ebonite disks held in position by swivel springs.

The instrument may be operated either directly by hand or indirectly from outside a dust chamber. In the first instance it is waved, with the axis of the cylinder vertical, up and down through the air; when a representative sample of air has been entrained the lid and slide are pushed over the ends and the cylinder left in a vertical position 1 to 3 hours. In the second instance the instrument is fixed in the dust chamber to permit free access of air to the cylinder, and the dusty air is circulated through it by an electric fan placed horizontally underneath. The lid and slide are pulled into place from outside the chamber by suitable strings. The lower limit of particle diameter detectable by this method is about 0.2 micron.

Green (242) emphasizes that the methods described are intended for research, for measurements of dust in fairly high concentration, not for routine or long-period estimations. The methods also provide a simple and accurate means of testing in the laboratory the efficiency of dust-sampling apparatus. They are most suitable for clouds containing not less than 1,000 particles per cubic centimeter, although they can be extended to clouds containing not less than 100 particles per cubic centimeter; they cover the whole size range down to 0.2-micron diameter. Green also describes methods for counting the particles under a microscope of high resolving power and for determining rapidly the size-frequency of particles by a comparator.

In an article on recent developments in methods of sampling dust Green (209) said that it is somewhat disconcerting to find in the literature dealing with the hazard due to mineral dusts a general lack of information about the intrinsic nature of the dusts as they exist in the air. He attributes this to the lack until recent years of accurage methods for gaining this information, although it is true that many data have been accumulated as a result of determinations with field instruments, but the value of these figures must be discounted owing to inherent defects in the instruments themselves. He gives a critical review of the available instruments and a method of testing them, including a method of generating in the laboratory dust clouds similar to those found in industry. Three types of instruments were selected for testing--the Greenburg-Smith impinger, the "standard United States instrument"; the konimeter, in general use in South Africa; and the Owens jet dust counter, often used in England and many other countries. He concludes that none of these instruments

would give accurate date about either the number or size-frequency of particles in dusts, nor could they be used for fundamental work, and for comparative work they would need very careful preliminary calibration in the laboratory against dust of similar character to those found in the industry under investigation. He and his coworker Watson developed a modified thermal precipitator which they claim satisfies most of the requirements of a standard instrument for both fundamental and comparative work; it yields accurate information about the number of particles and their size frequency and, to a certain extent, about their shape. A fundamental investigation would also require that the nature of the particles be determined quantitatively; the thermal precipitator records can be mounted for petrological examination, but owing to the difficulty of identifying the nature of particles below about 2 microns in diameter this part of the problem still awaits solution.

Electrostatic Methods

The fact that electrically charged bodies in an electric field tend to migrate to one of the electric poles has long been known (176). This principle of the precipitation of suspended matter by electricity has been applied commercially to the collection of industrial dusts by Cottrell (243), who reduced to engineering practice the fundamental processes developed by earlier investigators; adaptation of the Cottrell process to determination of dust in air is under consideration by engineers interested in dust control. In 1919 Bill (244) reported the use of the electrostatic method for sampling dust in air. The essential feature of this instrument is a collecting electrode, consisting of a metal tube, and an ionizing electrode. The dust particles are charged by the ionizing electrode and travel to the collecting electrode, where they are deposited. The collection system, however, is only a small part of the complete apparatus. In addition, it includes a high-tension transformer, a rectifying device for the high-potential alternating secondary current, a source of alternating current to excite the transformer, and a pump or fan for passing the air to be studied through the electrically charged field.

In 1923 Drinker, Thompson, and Fitchet (245) described a greatly simplified form of electrostatic apparatus having a dust-removal efficiency of nearly 100 percent. In 1925 Drinker and Thompson again simplified this apparatus (246). Current is supplied by four alkali storage cells, from which both the precipitator and suction-fan motor derive the necessary current. The entire apparatus weighs approximately 13 pounds and appears to be an instrument with considerable practical application (176).

Resistance

This method makes use of the fact that the resistance of a filtering medium increases as its pores become filled with dust. The apparatus, known as the "Anderson and Armspach Dust Determinator" (246), consists of a holder in which a piece of filter paper or other porous fabric is clamped. Air is drawn through the paper at a constant rate and the difference of pressure between the two sides of the paper is determined by a U tube, the arms of which open into the holder, one on each side of the paper. The manometer reading

indicates the difference of pressure existing between the two sides of the filter. As the paper clogs more pressure is required to keep the air passing at the same rate, and the manometer reading increases. This instrument was developed for use in testing air washers by the research laboratory of the American Society of Heating and Ventilating Engineers. It has no hygienic purpose because it gives no information on particle size and quantity of dust encountered. The correlation between the actual dust content of the air and the resistance to passage through a filter paper would entail considerable time and arduous labor, if it could be done at all.

Impinging Methods

Another method impinges a definite sample of air on a prepared surface. This apparatus has the advantage that a definitely known volume of air is sampled, and by the velocity of the impact a greater percentage of the dust is caught and may be estimated. Numerous variations of impinging the air on prepared surfaces have been developed, most of which have not been highly efficient.

Konimeter.--In 1916 Kotze (248) called attention to an instrument which he called the konimeter. This consists of a chamber, one side of which is a vaseline-coated glass plate, and an impinging orifice, which is perpendicular to the slide. The air is sucked out of the chamber by a cylinder and a spring-actuated piston. The only means of ingress of air is through the impinging orifice, and when the air enters the chamber at high velocity in this manner the dust is deposited in the form of a spot on the greased plate. The dust may be counted under the microscope, using a ruled eyepiece. The method of examining konimeter dust spots by opaque illumination, as practiced until recently in South Africa (249), not only gave unreliable but also misleading results and has been replaced by examination of the dust spots under transmitted polarized light.

Hill dust counters.--Hill (214) devised two forms of dust sampling devices that use the impingement principle. The first, the photographic dust counter, consists of a metal frame supporting a metal funnel at one end and at the opposite end a photographic plate holder. An anemometer is placed in the funnel-shaped opening and a moistened photographic plate in the plate holder at the opposite end. Air is forced through the anemometer against the plate. After the usual photographic development the particles on the plate may be counted directly, or a print may be made and the particles enumerated. This method obviously has the same disadvantages as the other low-velocity impingement methods, to which is added the error introduced by the use of the photographic method.

Hill's (214) second instrument of the impinger type consists of a hand-actuated piston moving in an air cylinder, the only inlet to which is a nozzle one eighth inch in diameter. In front of this nozzle and fixed only a short distance from it is a microscope cover coated with an adhesive preparation. When the piston is drawn out a jet of air is impinged on the prepared slide, which catches the dust. By using 6 slides in series Hill found that the first slide caught only 62 percent of the dust. He assumed, however, that all the

dust was caught by the 6 slides, an assumption considered fallacious. This instrument is similar to the Kotze konimeter. Comparatively high velocity is necessary for deposition of dust in this manner.

Impinger dust-sampling apparatus.--In a comparative study by the United States Bureau of Mines and the United States Public Health Service (250) the dust-catching efficiency of the impinger was found to be high. Consequently its physical principles and characteristics were made the object of a special study; as a result a relatively satisfactory and fairly practical form of dust-sampling instrument, based on this principle, has been evolved (251). This device has the advantage of high dust-catching efficiency when air is sampled over the full range of dustiness (from relatively pure outdoor air to that found in very dusty coal-mining operations) at the relatively rapid rate of 28.3 liters (1 cubic foot) per minute. The dust is caught in a liquid medium in which it may be counted and analyzed microscopically, gravimetrically, and chemically (provided it is insoluble in water). Three forms of the instrument are described: Electrically driven, compressed-air-driven, and a hand-actuated form.

While using the impinger apparatus in a study of the hazards of rock drilling on building and subway construction work about New York City Fehnel (216) experienced difficulty in checking with the empirical method found effective by the United States Public Health Service in its study of the granite industry. He consulted other technicians and found that some modified the light by tilting or shading the mirror; he therefore tried a modification of the illumination. Other investigators, manufacturers of microscopical equipment, and microscopists who were consulted agreed that the standard procedure did not reveal the small particles, and the use of dark-field illumination was essential. Various combinations of magnifications and dark-field illuminations were demonstrated at Saranac Lake in April 1932, using a specially prepared silica dust of 3-micron average size. It was decided at that time that the various agencies interested would employ both light- and dark-field methods in studying various industrial dusts. So far, according to Fehnel (216), no attempt has been made to correlate the findings collectively. Two comprehensive studies employing both methods of counting showed a fair, consistent relation between counts on the same types of dust, so that it is possible to establish a conversion factor. The modified method has proved that technicians can check fairly consistently their own and others' counts on the same samples; moreover it reduces materially the time element necessary.

Fehnel (216) also calls attention to the value of determining particle-size measurements with dust counts. His first method employed the filar micrometer, using a dry preparation made by evaporating the sample collected in the impinger and examining under oil immersion. As such a procedure is very laborious, Green's method (252) of determining the particle size of paint and rubber pigments was adopted; this method requires more operations but eliminates the possibility of becoming mechanical when doing routine work, as is the case with the filar micrometer. It also speeds up materially the work of particle-size determinations. The percentage frequency of occurrence is plotted against particle size on Hazens' logarithmic paper, so that the curve

comes out a straight line, which makes it easy to interpolate. Fehnel (216) states that the interesting facts found so far on particle sizes are that the median or 50 percent of the industrial dusts studied are in the 1- to 3-micron size range and that 90 to 99 percent are less than 10 microns.

According to Hatch and Thompson (253), the impinger technic has provided valuable assistance in the study of the dust hazard, but because of the considerable amount of apparatus involved and the skill required in the quantification of samples it is not entirely satisfactory for routine plant control. Given a standard of permissible dustiness with a reasonable factor of safety, it may even be sufficient for routine plant control to know whether the dustiness associated with a particular process is above or below the standard; the ability to obtain this information quickly is more important than the accuracy of the determinations. As Mavrogordato (208) has pointed out, the plant operator does not want precise dust counts but rather data on which he can act. Because of the skill required in operation of the apparatus or in "quantification" of samples or because of other undesirable characteristics, the impinger, direct-vision konimeter, and other rapid methods of dust determination were not considered entirely satisfactory for the average industrial plant. A new method developed by Hatch and Thompson (253) appears to have many desirable features with respect to simplicity and rapidity in operation. An Owens counter, modified to permit the collection of eight samples direct onto a single glass slide, is used as the sampling instrument, and the "dust ribbons" are quantitated by matching against a series of standard ribbons under a comparison microscope. The method is calibrated in terms of the impinger. It is intended for rapid, approximate dust determinations only and is not proposed as a substitute for the impinger. It must be calibrated at the outset against that instrument, and the relationship should be checked from time to time. Data obtained with the Owens counter alone should not be regarded as constituting complete "legal" evidence of dust concentrations. As an adjunct to the impinger it may be used to measure the efficiency of dust-control equipment.

Modified Zeiss konimeter.--Since dust diseases are due to the physical or chemical action of certain dusts below a specific fineness it is desirable to measure independently the content of the finest dust particles in suspension in air without at the same time being burdened by the coarser and relatively harmless grains. This principle of selective dust estimation has been applied in the Zeiss konimeter (254). In this apparatus a sample of air is taken and all dust particles above a certain size are removed by filtration; the finest particles remaining in suspension are then deposited on a slide in the usual way. The apparatus consists of the standard Zeiss konimeter, supplemented by a special air filter, and a small pump to aspirate air through the konimeter. The air enters the sampling unit at the filter, which contains a number of glass beads, and passes through a narrow jet. The sampling disk is the same as in the original Zeiss konimeter, a glass disk secured in a ring, which can be turned about the konimeter to the 30 sections on the slide opposite the sampling jet in succession; up to 30 individual samples can thus be taken without dismantling or readjusting the whole apparatus. The electric motor is of standard design and can be run from batteries or from a direct-current supply.

The dust samples are examined in the usual way under a microscope, all particles being visible at the outset. After a preliminary examination a drop of tetralin added to the sample renders the quartz particles invisible, as their refractive index is virtually identical with that of tetralin. By a differential count it is possible to estimate the quartz content of a dust sample. The article mentions that this apparatus has been exhaustively tested in various dust researches in Europe and found to give reliable and reproducible results.

Comparative tests made with the Kotze and Zeiss instruments (255) under identical conditions revealed that the Zeiss has an efficiency 50 percent higher than the Kotze; therefore, in making determinations with the Zeiss konimeter the limit of safe concentration is increased from 300 to 450 particles per cubic centimeter.

Photometric estimation of konimeter dust samples.--In the November 1934 issue of Mining Magazine Franks and Tresidder (256) described a rapid photometric method of estimating the dust collected on treated konimeter slides; this method retains all the advantages of the konimeter and at the same time overcomes certain disadvantages--notably, those associated with counting the material in the dust spot. Counting is arduous and time-consuming; photometric estimations can be made in about one tenth the time required to count an average spot. Furthermore, according to Frank and Tresidder (256), the counting method is a purely arbitrary measure of the dangerousness of dusty air; equal value is placed on each particle, regardless of its size or siliceous nature. The photometric values are most sensitive to the size range that is most dangerous; this method also tends to differentiate the particles by giving high value to quartz and largely obviates errors in counting due to sector sampling, aggregation, fatigue, and personal error. The estimable range of dust concentration is extended to include dust concentrations found in blasting. Such a method should readily give data which, when correlated with clinical findings, should lead to a better identification of the dust hazard.

Physiological Methods

In addition to the above methods of determining the quantity and composition of dusts that occur in many industrial occupations it is important to distinguish those capable of causing pneumoconiosis. The obvious way to determine whether a substance can affect the human lung is to test its action on the lungs of animals, but according to Kettle (257), this method is not altogether satisfactory as it is laborious, expensive, and, above all, time-consuming. Whatever the technic employed for the introduction of dust into the lungs, all who have worked on experimental pneumoconiosis agree that the end lesion--the characteristic fibrotic nodule--cannot be produced in a few days or weeks but only in periods measurable in years rather than months; the method therefore has little value as a practical test. Kettle (257) divides the constituents of occupational dust into two groups--the active and the inert--according to their behavior when injected into the subcutaneous tissues; this grouping corresponds with clinical and industrial experience. The active dusts cause an acute inflammation with necrosis of tissue and

subsequent fibrosis, whereas the inert dusts give rise to nothing more than a mild and transient reaction. Further, if animals in which such lesions have been produced are infected intravascularly with tubercle bacilli clear evidence is obtained that the active dusts determine a local settlement and proliferation of the bacilli out of all proportion to that seen in the tissues generally and in the reactions surrounding the inert dusts. This technic provides a method for testing the capacity of a dust to modify an infection; however, Kettle (257) states that the claim that it tells whether the same substance can produce fibrosis of the lung is perhaps less legitimate, as there is an obvious difference between the injection of a substance into the tissues, with all the trauma involved, and its introduction into the lungs by the natural routes. He has found, however, that particulate matter suspended in normal saline may be injected directly into the lungs through the trachea without producing undue trauma to the pulmonary tissues. Particles introduced into the lungs in this way are picked up by phagocytes just as are the particles of dust inhaled in the air, and in due course some of the dust containing phagocytes reach the extrapulmonary lymph nodes. In human silicosis the earliest lesions are found in the root glands as the result of this process; the same is true in experimental pneumoconiosis. It does not matter how the dust reaches the lungs; although the mode of introduction possibly may have some relation to pulmonary lesions obviously it can have no influence on the glandular deposits produced entirely by natural means.

Kettle (257) found in his experiments a striking difference in the reactions occurring in the extrapulmonary lymph nodes according to whether the material introduced into the lungs was an active or an inert dust. If the injected dust was inert it remained in the substance of the pulmonary lymph nodes without causing tissue reaction and without exciting the attention of other phagocytic cells. If the dust was active, as soon as it was liberated by the death of the phagocyte it was ingested by fresh cells which appeared in such numbers as to disorganize completely the structure of the node. This activity was progressive and eventually led to the formation of the characteristic acellular nodule, although it might take a year or more. However, Kettle found it was necessary to wait for the end lesion to form in the lymph nodes before he could reach a conclusion regarding the nature of the dust; within 3 months a microscopic examination revealed such significant changes as to make diagnosis possible. The Colliery Guardian (258) points out that application of the method on a large scale might result not only in a definite preliminary classification of dusts but in the establishment of standards by which any samples could be tested.

In an investigation of the cellular response of lymph nodes to various dust suspensions introduced into lymphatics Stüber (259) found that cellular response of the lymph nodes to the injection of dusts containing considerable free silica is essentially different from that to other particulate material, the latter being phagocytosed only by normal lymph phagocytes. Some silicates produced a stimulation at the beginning with later slight changes in the cytoplasmic structure of the host cells. He described the response of the phagocytic system of lymph nodes to the injection of silica and the characteristics of the silica-containing phagocytes; these are identified biologically as

modified endothelial lymph phagocytes. The silica-containing cells lose much of their phagocytic power toward other particulate matter. Phagocytes that answer the description of the silica-containing cells in lymph nodes as produced in these experiments could be found in air spaces in cases of experimental as well as industrial silicosis of the lungs. It appears possible that the lymph-node injection method may be developed into a rapid means of determining the toxicity of certain dusts.

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BUREAU OF MINES,

WASHINGTON, D. C.

I. C. 6841

May 1935

Department of the Interior

UNITED STATES BUREAU OF MINES
John W. Finch, Director

INFORMATION CIRCULAR

PROCEDURE FOR TESTING EXPLOSIVES FOR ACCEPTABILITY FOR USE IN FOREST SERVICE WORK

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

PROCEDURE FOR TESTING EXPLOSIVES FOR ACCEPTABILITY FOR USE IN FOREST SERVICE WORK 1/

The fundamental tests to determine the acceptability of an explosive, and subsequent tests to determine the conformity of a lot of an explosive with its representative basic sample in accordance with the requirements of this circular shall, except for easily performed field tests, be made by the U.S. Bureau of Mines.

DEFINITION OF AN ACCEPTABLE EXPLOSIVE

An acceptable explosive is a detonating explosive that has been authenticated by the U.S. Bureau of Mines as being suitable, safe, and efficient for the performance of Forest Service work when used in accordance with the requirements of this circular.

Explosive mixtures of oxidants and combustibles of the gunpowder type, explosives to be compounded at the place of use, compressed and liquefied gases, and liquid explosives are not acceptable for Forest Service use.

ACCEPTABILITY TESTS

An explosive may be tested to determine (1) its basic data for admission to and its position upon the acceptable list, and (2) (when the Forest Service exercises its right to have explosives to be furnished on bids tested by the Bureau of Mines) its conformity to the type, class, and grade (with its attendant characteristics), to which the basic sample was assigned. The methods of determining this conformity of an explosive are described herein.

The items constituting the complete acceptability test which determines the admission of an explosive to the acceptable list of explosives for Forest Service work are listed under fees, which are as follows:

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List of Fees[2]

For complete tests for:

1. Fire weather acceptable explosives $78.00

2. Acceptable explosives that are not required to pass the fire-setting test. 74.00

The items under (1) are as follows:

(a) Chemical analysis. 25.00

(b) Physical examination (including cartridge count) 1.00

(c) Three test shots in the ballistic pendulum to determine the unit deflective charge 20.00

(d) Three rate-of-detonation tests, in paper tubes 5.00

(e) Water-resistance test, without wrapper 5.00

(f) Explosion-by-influence test (halved cartridge method). . . . 4.00

(g) Pendulum friction test, to determine sensitiveness to frictional impact. 7.00

(h) Freezing test, by crusher board. 7.00

(i) Fire-setting capacity. 4.00

Other tests:

(j) One gage test, to determine the gaseous products of explosion. 15.00

(k) Lead-plate test of detonators or electric detonators 4.00

To be admitted to the Forest Service list of acceptable explosives that are not required to pass the fire-setting test (listed as 2 above) an explosive must be able not only to pass items (g) and (h), but it must continue to possess the characteristics shown in items (a) to (f), inclusive, with tolerances. The same is required for the list of fire weather acceptable explosives (listed as 1 above), and in addition the explosive must be able to pass item (i).

2/ These fees conform to those promulgated in Bureau of Mines Schedule 1-B, Procedure for Testing Explosives Used in Metal Mines, Tunnels, Quarries and Other Engineering Operations, with Test Requirements and Schedule of Fees, 1926, 3 pp.

ACCEPTABLE EXPLOSIVES NOT TO BE CONSIDERED AS PERMANENTLY ACCEPTABLE

After further experiments and conferences the Forest Service may find it advisable to adopt additional and more severe tests to which all acceptable explosives may be subjected in the hope that, through the use of only such explosives as pass the more severe tests, the lives of blasters may be safeguarded better and the menace of fire eliminated.

The manufacturer of an acceptable explosive may withdraw it from the list, and he is urged to do so when replacing an acceptable explosive with one of superior qualities.

CONDITIONS UNDER WHICH TESTS WILL BE MADE

(1) Tests will be made at the Explosives Testing Station of the Bureau of Mines, at Bruceton, Pa., and the conduct of the tests shall be entirely in the hands of the Bureau's representative in charge of the tests.

(2) Applications for tests must be addressed to the Forester, U.S. Forest Service, Washington, D.C., in accordance with the instructions of that Bureau. The formulas of explosives for which tests are desired must accompany the applications for tests.

(3) The manufacturer or applicant granted permission to have tests made shall ship prepaid and consign to the Explosives Engineer, Bureau of Mines Testing Station, Bruceton, Pa., each explosive in cartridge sizes and quantities as requested, together with the original bill of lading, and all copies thereof. For the complete official test 50 pounds of each explosive is required. Cartridged explosives should be 1-1/4 by 8 inches in size. To facilitate the making of tests on free-flowing bag powders samples of these should also be submitted in 1-1/4-by 8-inch cartridges.

(4) If in the course of making the complete acceptability test an explosive fails on any item of the test that it should pass, or an unfavorable characteristic develops, the test shall be discontinued at that point; in such a case, or if the explosive is withdrawn, charges will be assessed for all the items of the test that have been made up to the time of the failure or withdrawal, plus a handling charge of five dollars ($5.00). The balance will be returned to the applicant.

(5) The results of tests are to be considered confidential within the applicant's organization and are not to be made public prior to official publication by the Forest Service.

PRESCRIBED CONDITIONS FOR USE OF ACCEPTABLE EXPLOSIVES

1. That the explosive is in all respects similar to the basic sample authorized for the acceptable list.

2. That the explosive shall be stored under such conditions as to avoid changes in its characteristics as much as possible.

3. That the explosive, if frozen, shall be thoroughly thawed in a safe and suitable manner before use.

4. That, in blasting with the explosive, electric detonators are used of not less efficiency than a No. 6, containing a charge of 1-gram of a mixture by weight of 80 parts of mercury fulminate and 20 parts of potassium chlorate.

5. That the charge shall not be fired by fuse.

6. That the charge shall not be fired without stemming or with combustible stemming, but shall be firmly confined with fireclay or other incombustible stemming.

7. That when cartridged explosives are used in blasting the "wrapper" of the cartridge shall always be included as part of the charge.

TEST REQUIREMENTS OF EXPLOSIVES FOR FOREST SERVICE WORK

Each charge shall be fired with an electric detonator of not less efficiency than a No. 6 detonator, whose detonating charge consists, by weight, of 80 parts of mercury fulminate and 20 parts of potassium chlorate (or their equivalent).

The failure of two or more charges to detonate or explode completely in the course of the official tests when fired with a suitable detonator under confinement equal to or greater than 1 atmosphere will be considered an unfavorable result.

The explosive must be in such condition that the chemical and physical tests do not show any unfavorable results. An explosive will be considered unsatisfactory if it is not chemically stable, if it shows leakage of liquid explosive ingredient, or if it is in such condition that exudation of liquid explosive ingredient would occur in handling, transportation, and storage.

REVIEW OF TEST DATA AND ASSIGNMENT OF AN EXPLOSIVE TO ITS TYPE, CLASS, GRADE, AND USE

After a sample of an explosive has been tested the data obtained will be reviewed to establish the type, class, and grade of the explosive, or, in the case of a re-test, its conformity with the basic sample. The explosives which have already been authenticated by the Forest Service are of the nitric ester or nitrosubstitution types, or mixtures which behave as such. If necessary,

additional types will be established from the chemical analyses of the samples tested and chiefly on the basis of the ingredient used for sensitizing the explosive.

In establishing the conformity of an explosive after re-test to the type, class, and grade to which the basic sample was assigned the tolerances promulgated by the Bureau of Mines (for permissible explosives) will be applied to its chemical constituents other than moisture. These tolerances provide for reasonable limits of variations in the results of analyses and tests as they are repeated upon samples of acceptable explosives.

The ingredients of an acceptable explosive shall be considered to be those substances recorded as found by the Bureau of Mines in the original sample.

The basic sample will not be considered acceptable if it contains over 2 percent of moisture. A tolerance of 1.5 percent will be applied on a retested sample.

Table I contains the numerical values that will be applied for various quantities of a constituent (other than moisture) found in a retested sample.

TABLE I.-- Tolerances for other ingredients or their equivalents in quantities not exceeding 60 percent 1/

Quantity of constituent From -	Quantity of constituent To -	Limit of variation of total explosive	Quantity of constituent From -	Quantity of constituent To -	Limit of variation of total explosive
Percent	Percent	Percent	Percent	Percent	Percent
0.0	1.4	1.0	23.5	26.4	2.0
1.5	2.4	1.1	26.5	30.4	2.1
2.5	5.4	1.2	30.5	33.4	2.2
5.5	6.4	1.3	33.5	37.4	2.3
6.5	9.4	1.4	37.5	40.4	2.4
9.5	11.4	1.5	40.5	44.4	2.5
11.5	14.4	1.6	44.5	47.4	2.6
14.5	17.4	1.7	47.5	51.4	2.7
17.5	20.4	1.8	50.5	54.4	2.8
20.5	23.4	1.9	54.5	57.4	2.9
			57.5	60.0	3.0

1/ Except for (a), all ingredients exceeding 60 percent and (b), carbonaceous combustible material regardless of quantity, the tolerance for (a) and (b) shall be equal to 3 percent. (c) Ammonium nitrate, ammonium chloride, and ammonium sulphate; the tolerance will be applied to the sum of these ingredients which will be reported as commercial ammonium nitrate. The sum of the ammonium chloride and the ammonium sulphate will be reported separately in a note, and the tolerance applied to their sum will be 4 percent of the commercial ammonium nitrate reported as present in the basic sample, except in those cases where the tolerance thus applied would be less than for a separate ingredient for, in this last mentioned case, the tolerance for "other ingredients" would apply.

Cartridge Count

The cartridge count (that is, the number of cartridges in a 50-pound case) will be computed from the physical examination and/or by actual count of the cartridges in a 50-pound case. A total variation of 10 cartridges will be allowed for cartridge counts below 130, and for 130 or over a total variation of 9 percent will be applied. As far as possible, the established variations in cartridge count will be in accordance with the variations now used commonly by the manufacturers, which are as follows:

	Cartridge count per 50-pound case
Gelatinized explosives	85-95
	88-98
	93-103
	95-105
Ungelatinized explosives	105-115
	107-117
Ungelatinized explosives, low-density	124-136
	145-159
	164-180

Grade

The grade of basic sample will be established on the basis of the unit deflective charge determination in accordance with table II.

TABLE II.-- Grade and unit deflective charge of acceptable explosives

Grade	Unit deflective charge		
	Ungelatinized	Gelatinized	
		Ammonia	Straight
20	260-285	-	
30	245-265	270-290	
40	225-250	255-270	245-275
50	205-225 1/		
60	205-230	225-250	210-235

1/ Straight nitroglycerin dynamite.

As an example of the use of the above table, suppose that the unit deflective charge determined on a basic sample of an ungelatinized explosive were 229; then the grade would be 40 percent.

Use

The physical characteristics found for a basic sample of explosive will be compared with those recorded in Forest Service table III 3/ and will then be recommended for use along with other explosives having similar characteristics.

BASIC SAMPLE

The term basic sample as used in this circular refers to the explosive possessing the type, class, and grade characteristics sought, as recorded in Forest Service table III, and the composition by chemical analysis recorded in the files of the Bureau of Mines. The number of basic samples may increase as new explosives are admitted to the acceptable list.

3/ Characteristics of Acceptable Explosives for Forest Service Use: Filed in Washington Office of the U.S. Forest Service.

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UNITED STATES BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

GOLD AND SILVER CUSTOM PLANTS

BY

E. D. GARDNER

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

GOLD AND SILVER CUSTOM PLANTS[1/]

By E. D. Gardner[2/]

A custom gold and silver plant is one that treats ores for a fee. Usually such plants are located in mining districts and treat local ores. Ores of milling grade generally can stand only moderate transportation charges. These plants are scattered throughout the West. Most plants now doing a custom business originally were built by mining companies to handle ores from their own mines. As excess mill capacity became available ores from neighboring properties were treated, mainly as an accommodation. Later, as their own ore bodies became depleted, the mills were operated entirely on a custom basis. A few plants pull ore from their own mines only when the supply of custom ore is insufficient to keep the mill operating. Some of the present custom plants were built for custom work alone. Although built originally to treat the ores of the Golden Cycle mine, the Golden Cycle plant at Colorado Springs, Colo., soon became a custom mill and has been operating successfully for many years. It is the largest gold mill in the Western States and treats Cripple Creek ores, from which most of its tonnage still comes. The plant is equipped to treat a great variety of ores and receives shipments from a wide area. It competes with smelters in Colorado, as it has a roasting plant to prepare sulphide concentrates for treatment in its cyanide plant. Most custom mills, however, are not adapted for more than one or two kinds of ore.

Gold occurs in its ores both in the metallic state (free) and locked up in sulphides. It also occurs in a few places, notably at Cripple Creek and a few other Colorado districts, as tellurides. When the gold occurs in the native state, the ores is said to be free-milling and can be recovered by amalgamation. Usually, however, some subsidiary treatment is required to make a satisfactory extraction. Amalgamation generally was followed by tabling in the earlier mills; at present, flotation has replaced tables at many places. As depth is reached in mining and the workings extend below the oxidized zone the character of the ore usually changes, or, as the miners say, "it gets base". Since the advent of flotation, the average recovery of gold in base ores has been improved greatly. Cyanidation is applied to some types of both gold and silver ores. The recovery by cyanidation is in general considerably higher than by other methods in vogue and in addition has the advantage of making a finished product which can be sold directly to the mint, thus obviating smelting charges on concentrate and discounts

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2/ Supervising engineer, U. S. Bureau of Mines Southwest Experiment Station, Tucson, Ariz.

on the price of gold made by the smelting companies. The disadvantage of cyanidation is a higher first cost of plant and a higher operating cost.

Silver seldom occurs in the native state in this country, and silver ores are not amenable to amalgamation; other methods for treating gold ores are equally suitable for silver. Most gold ores contain some silver, and silver ores usually contain some gold. Generally a higher recovery is made of the gold than the silver in ore containing both metals. Although at most gold mines associated metals are relatively unimportant, base metals in silver ores may constitute a large part of their value. There are very few mines in the United States in which the values are almost entirely silver. Lead and copper mines are the most important producers of silver.

The following table shows the gold and silver custom mills in the Western States in operation at the time of field trips by the author in 1933 and 1934.

It will be noted from the table that the total daily capacity of 30 of the 31 mills listed is 3,689 tons. Some of the mills, however, were not being operated at near capacity. The capacity for individual plants is 5 to 2,000 tons per day. Custom charges ranged from $1.75 to $9.60 per ton for ores, depending upon the character of the ores treated, the method used, and to some extent what the traffic would bear. Clean-up charges on small lots ranged from $5.00 to $15.00. At many of the smaller plants amalgam and concentrate were turned over to the shipper for marketing. The recovery at some of these plants was as low as 50 percent. Other companies paid for the ores eceived at 80 to 96 percent of its assay value; the higher brackets were at cyanide plants. Flow sheets ranged from straight amalgamation to amalgamation with tabling or flotation to straight cyaniding. Except at the Golden Cycle Mill lead, copper, or other base metals which might be contained in the ore are not paid for.

Since the field trips were made some of the mills listed have closed, and others have opened for business. Moreover, other mills not listed have begun to take custom ores. Many districts where the custom mills are situated are served adequately by these plants. Some of the small plants, however, were constructed poorly and run by hit-or-miss methods.

In a number of gold-mining districts gold-ore deposits are being discovered the mineral content of which does not warrant expenditures on development work, as there is no mill in the vicinity where the ore can be concentrated, and no single property has enough ore developed to warrant building a mill. These districts offer opportunities for the local miners and property owners to cooperate in the erection of custom mills and thus encourage mine developments on deposits that are valueless without local means for concentration and gold extraction.

A list of a number of custom mills in Arizona, California, Colorado, Nevada, and New Mexico and details as to the rates and deductions for treatment of gold ores and concentrates are given in the following table. This list does not include all of the mills in these States or those in Wyoming, Utah, Idaho, and other Western States. It is believed, however, that the publication of this partial list will be of interest to many.

Custom rates		Remarks
Classification	Per ton	
Fairview lease.	$3.50	90 percent of gold at $33 oz. and
Others.	4.50	90 percent of silver at $0.60 oz. paid for. No deduction for moisture.
Up to $6.00 ore	4.50	90 percent of gold at $33 oz. and
$6.00 to $15.00.	4.50 to 6.00	90 percent of silver at $0.60 oz. paid for. No deduction for moisture.
Flat rate.	3.50	Amalgam and concentrate delivered to shipper. $15 clean-up charge for each lot.
Bullion mine ore only.	-	Milling cost, $1.46 ton.
Am.	2.00	Shipper given bullion and paid 70-percent
Am. & Cy.	4.00	heads to cy. $5 clean-up charge for each lot.
Flat rate.	11.00	Concentrates only treated.
-	-	-
Small lots.	3.00	Shipper given amalgam and concentrate.
Large lots.	2.50	
-	-	-
-	-	-
100-ton lots.	3.00	-
Flat rate.	4.00	Clean-up charge of $10 for all lots under 10 tons. Shipper given amalgam and concentrate.
do.	2.40	-
100-ton lots.	1.75	Clean-up charge of $15 on all lots under
75-ton lots.	2.00	75 tons. Tailings, stamp mill purchased on 50-percent assay value.
-	-	-
-	4.50	-
Flat rate.	6.00	-
-	-	-

Continued on page 4.

Mill	Date	Location	Capacity, Daily total	Ave for
Tom Reed	1934	Oatman, Ariz.	300	
Big Jim	1934	do.	50	
Katherine	1934	Chloride, Ariz.	200 ?	
Congress	1934	Morristown, Ariz.	100	
Forester	1934	Salome, Ariz.	5	
Hillsboro	1934	Hillsboro, N. Mex.	10	
Golden Cycle	1934	Colorado Springs, Colo.	2,000	
St. Joe	1934	Boulder, Colo.	67	
Watrous	1934	Silver Plume, Colo.	30	
War Dance	1934	Blackhawk, Colo.	25	
Farr	1934	do.	45	
Argo	1934	Idaho Springs, Colo.	150	
Gilpin	1934	do.	50 ?	

1/Am stands for Amalgamation; Tb, Tabling; R, C
Miscellaneous ores. 5/Miscellaneous ores: $19.5
50 percent, 1 to 5 oz.; 65 percent, 5 to 10 oz.
first 5 oz., 92-1/2 percent of difference for s

Mill	Date	Location	Capacity, tons: Daily total	Capacity, tons: Available for custom ores	Type of mill[1/]	Recoveries made, percent: Gold	Recoveries made, percent: Silver	Percentage of metals paid for: Gold	Percentage of metals paid for: Silver	Custom rates: Classification	Custom rates: Per ton	Remarks
Tropico	1934	Rosamond, Calif.	50 2/	50	Cy.	90+	90+	90+	90+	Fairview lease. Others.	$3.50 4.50	90 percent of gold at $33 oz. and 90 percent of silver at $0.60 oz. paid for. No deduction for moisture.
Elephant & Eagle	1934	Mojave, Calif.	50	40	Cy.	90+	90+	90+	90+	Up to $6.00 ore $6.00 to $15.00.	4.50 4.50 to 6.00	90 percent of gold at $33 oz. and 90 percent of silver at $0.60 oz. paid for. No deduction for moisture.
Queen Lil	1934	Nevada City, Calif.	25	25	Am., Tb. & Fl.	-	-	-	-	Flat rate.	3.50	Amalgam and concentrate delivered to shipper. $15 clean-up charge for each lot.
Hoge	1934	do.	50	50	R. & Fl.	93	-	-	-	Bullion mine ore only.	-	Milling cost, $1.46 ton.
Hobo Springs	1934	Hobo Springs, Calif.	10	10	Am.&/or Cy.	70	-	0	0	Am. Am. & Cy.	2.00 4.00	Shipper given bullion and paid 70-percent heads to cy. $5 clean-up charge for each lot.
Amador Reduction	1934	Jackson, Calif.	-	-	Cy.	-	-	$94\frac{1}{2}$	-	Flat rate.	11.00	Concentrates only treated.
Big Butte	1934	Randsburg, Calif.	12	12	Am.	-	-	-	-	-	-	-
Sonora	1933	Sonora, Calif.	15	15	Am. or Tb.	-	-	-	-	Small lots. Large lots.	3.00 2.50	Shipper given amalgam and concentrate.
Brand & Ellis	1933	Victorville, Calif.	30	30	Am., Tb. & Fl.	-	-	80	-	-	-	-
Baker & Bemard	1933	Barstow, Calif.	10	10	Am. & Tb.	80	-	-	-	-	-	-
Mar John	1933	Sheep Ranch, Calif.	30	30	Fl.	82	-	-	-	100-ton lots.	3.00	-
Cyrus Noble	1934	Searchlight, Nev.	25	25	Am. & Tb.	60 to 83	-	-	-	Flat rate.	4.00	Clean-up charge of $10 for all lots under 10 tons. Shipper given amalgam and concentrate.
Trimble	1934	Silver City, Nev.	30	30	Am.	80	-	80	-	do.	2.40	-
Donovan	1934	do.	35	35	Am. & Cy.	96	-	-	-	100-ton lots. 75-ton lots.	1.75 2.00	Clean-up charge of $15 on all lots under 75 tons. Tailings, stamp mill purchased on 50-percent assay value.
Recovery	1934	Virginia City, Nev.	45	45	Am. & Fl.	-	-	-	-	-	-	-
W. & M.	1934	Sodaville, Nev.	45	45	Am., Tb. & Fl.	90	-	90	-	-	4.50	-
Black Mammouth	1934	Silver Peak, Nev.	40	20	Am. & Fl.	-	-	80	-	Flat rate.	6.00	-
Rodgers	1934	Seven Troughs, Nev.	10	10	Am. & Tb.	95 3/	-	-	-	-	-	-

Continued on page 4.

Mill	Date	Location	Capacity, tons: Daily total	Capacity, tons: Available for custom ores	Type of mill[1]	Recoveries made, percent: Gold	Recoveries made, percent: Silver	Percentage of metals paid for: Gold	Percentage of metals paid for: Silver	Custom rates: Classification	Custom rates: Per ton	Remarks
Tom Reed	1934	Oatman, Ariz.	300	150	Cy.	98	-	95	-	25-ton lots.	$4.00	-
										75-ton lots.	3.80	-
										100-ton lots.	3.60	-
Big Jim	1934	do.	50	10	Cy.	98	-	95	-	Small lots.	4.00	-
Katherine	1934	Chloride, Ariz.	200 ?	125	Cy.	-	-	96	33	100-ton lots.	5.50	-
Congress	1934	Morristown, Ariz.	100	100	Cy.	-	-	95	-	Up to $10 ore.	3.50	-
										$10 to $15 ore. ($0.50 for each $5 increase)	4.00	-
Forester	1934	Salome, Ariz.	5	5	Am. & Fl.	80 ?	-	-	-	Flat rate.	5.00	Clean-up after each lot and wait for returns.
Hillsboro	1934	Hillsboro, N. Mex.	10	10	Fl.	-[4]	-	-	-	do.	2.50	do.
Golden Cycle	1934	Colorado Springs, Colo.	2,000	2,000	Tb. & Fl. or R. & Cy.	88[4]	-	[5]	[6]	Up to $8 ore.	2.50	Milling cost, 1932 $0.5039. Added sampling charge of $5 on all lots less than 10 tons. $2.50 for each extra lot in car.
										$8 to $10 ore.	3.00	
										$10 to $40 ore.	4.00 to 5.50	
						-	-	92[7]	-	Up to $4 ore.	1.95	Freight, $0.60.
										$5 to $8 ore.	2.50	Freight, $0.75.
										$10 to $100 ore.	5.70 to 9.60	Includes freight.
St. Joe	1934	Boulder, Colo.	67	40	Am., Fl. & Tb.	92	-	85	50 to 90	Up to $8 ore.	2.50	
										$8 to $10 ore.	3.00	
										$10 to $40 ore.	4.00 to 6.00	
Watrous	1934	Silver Plume, Colo.	30		Am., Tb. & Fl.	92½	-	-	-	-	2.25	Concentrate and bullion given shipper.
War Dance	1934	Blackhawk, Colo.	25	25	Tb. & Fl.	-	-	-	-	Lots less 100 tons.	2.25	do.
										Lots over 100 tons.	2.50	
Farr	1934	do.	45	45	Am. & Fl.					-	2.25	do.
Argo	1934	Idaho Springs, Colo.	150	150	Tb. & Fl.	90	-	-	-	Up to $10 ore.	2.00	do.
										Over $10 ore. (Lots of 100 tons)	2.50	
Gilpin	1934	do.	50 ?	50	-	-	-	-	-	-	5.00	Clean-up charge of $5 for each lot.

1/Am stands for Amalgamation; Tb, Tabling; R, Cloths, or riffles; Fl, Flotation; Cy, Cyanidation. 2/Being enlarged to 75 tons daily, September 1934. 3/ Claimed. 4/ Miscellaneous ores. 5/Miscellaneous ores: $19.50 up to 0.5 oz., $20 over 0.5 oz., plus 90 percent of difference mint price and $20.67. 6/ None paid for under 1 oz.; 50 percent, 1 to 5 oz.; 65 percent, 5 to 10 oz.; 75 to 95 percent, 10 to 100 oz. 7/ Cripple Creek ores: $20 oz. plus 95 percent difference mint price and $20.67 for first 5 oz., 92-1/2 percent of difference for second 5 oz. and 90 percent of difference of all gold in product over 10 oz. per ton.

tons ilable : custom ores	Type of mill 1/	Recoveries made, percent: Gold	Recoveries made, percent: Silver	Percentage of metals paid for: Gold	Percentage of metals paid for: Silver	Custom rates: Classification	Custom rates: Per ton	Remarks
150	Cy.	98	-	95	-	25-ton lots.	$4.00	-
						75-ton lots.	3.80	-
						100-ton lots.	3.60	-
10	Cy.	98	-	95	-	Small lots.	4.00	-
125	Cy.	-	-	96	33	100-ton lots.	5.50	-
100	Cy.	-	-	95	-	Up to $10 ore.	3.50	-
						$10 to $15 ore. ($0.50 for each $5 increase)	4.00	-
5	Am. & Fl.	80 ?	-	-	-	Flat rate.	5.00	Clean-up after each lot and wait for returns.
10	Fl.	-	-	-	-	do.	2.50	do.
2,000	Tb. & Fl. or R. & Cy.	88 4/	-	5/	6/	Up to $8 ore.	2.50	Milling cost, 1932 $0.5039. Added sampling charge of $5 on all lots less than 10 tons. $2.50 for each extra lot in car.
						$8 to $10 ore.	3.00	
						$10 to $40 ore.	4.00 to 5.50	
		-	-	92 7/	-	Up to $4 ore.	1.95	Freight, $0.60.
						$5 to $8 ore.	2.50	Freight, $0.75.
						$10 to $100 ore.	5.70 to 9.60	Includes freight.
40	Am., Fl. & Tb.	92	-	85	50 to 90	Up to $8 ore.	2.50	
						$8 to $10 ore.	3.00	
						$10 to $40 ore.	4.00 to 6.00	
	Am., Tb. & Fl.	92½	-	-	-	-	2.25	Concentrate and bullion given shipper.
25	Tb. & Fl.	-	-	-	-	Lots less 100 tons.	2.25	do.
						Lots over 100 tons.	2.50	
45	Am. & Fl.					-	2.25	do.
150	Tb. & Fl.	90	-	-	-	Up to $10 ore.	2.00	do.
						Over $10 ore. (Lots of 100 tons)	2.50	
50	-	-	-	-	-	-	5.00	Clean-up charge of $5 for each lot.

loths, or riffles; Fl, Flotation; Cy, Cyanidation. 2/Being enlarged to 75 tons daily, September 1934. 3/ Claimed. 4/) up to 0.5 oz., $20 over 0.5 oz., plus 90 percent of difference mint price and $20.67. 6/ None paid for under 1 oz.; ; 75 to 95 percent, 10 to 100 oz. 7/ Cripple Creek ores: $20 oz. plus 95 percent difference mint price and $20.67 for econd 5 oz. and 90 percent of difference of all gold in product over 10 oz. per ton.

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Revised
April 1936

Department of the Interior

UNITED STATES BUREAU OF MINES
John W. Finch, Director

INFORMATION CIRCULAR

PROSPECTING FOR LODE GOLD

BY

E. D. Gardner
Supervising Engineer, U. S. Bureau of Mines

AND

LOCATING CLAIMS ON THE PUBLIC DOMAIN

BY

Fred W. Johnson
Commissioner of the General Land Office

I.C. 6843
Revised
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INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

PROSPECTING FOR LODE GOLD[1]

By E. D. Gardner[2]

CONTENTS

INTRODUCTION

The Bureau of Mines receives many inquiries concerning favorable areas in which to prospect for gold, procedure to be followed, equipment required, and allied subjects. This circular has been prepared for use in reply to these inquiries and is a preprint of part of a bulletin to be issued later on "Equipping, Developing, and Operating Small Gold Mines."

The increased interest in gold mining manifested during the past few years (1932-1935) has stimulated prospecting. Many adventurers have taken to the field to search for new gold deposits. A large percentage of them have had no previous experience in prospecting for lode gold; this paper has been written with the hope that it might assist these newcomers.

PROSPECTING

A majority of the metal mines in the United States have been discovered by qualified prospectors who were searching for valuable minerals at the time. Chance, however, always

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U.S. Bureau of Mines Information Circular 6843."

2 Supervising engineer, Southwest Experiment Station, U.S. Bureau of Mines, Tucson, Ariz.

has played a large part in finding mineral deposits. Some of the discoveries of the past were made by men on other errands, such as rounding up burros or hunting game. Accidental discoveries of ore bodies have been made in building roads and trails and in excavating for mine structures. Evidence of ore has been brought to the surface by burrowing animals and by ants; gold found in the craws of fowl has led to discoveries of deposits. Important discoveries have been made by men who had no knowledge of rocks or minerals; on the other hand, many ore bodies have been found by experienced prospectors, sometimes after hundreds of untrained men had already passed over the ground.

The prospector who carries on his work diligently and intelligently is of course more likely to be rewarded for his efforts than the lazy or unintelligent worker; nevertheless, it is obvious that if valuable deposits do not exist at the place being prospected none will be found. Conscientious and painstaking efforts to trace gold to its source usually disclose nothing more valuable than some narrow, unworkable seams; however, many deposits that were developed into profitable mines were found by this method of prospecting. Although some prospectors have made several lucky strikes, many others have spent their working lives searching for mineral without finding anything worth while. Probably only one prospector out of several thousand ever finds anything worth developing. Moreover, only 1 out of every 300 or 400 properties developed becomes a profitable mine.

Prospecting began in the Western States in the fifties as the miners looked for the source of gold found in placers. The search for gold has been continuous since that time; the number of prospectors in the field at any one time, however, has varied greatly. Except in some desert regions, practically all of the placer fields now being worked were discovered by old timers; most of the important gold districts also were found by early prospectors. Important discoveries of lode mines, however, have been made from time to time. Most of the area in the mining regions of the West has been gone over many times by prospectors, and nearly all of the easily found deposits have been located, but it is reasonable to expect that new gold mines will continue to be found. Most of the future discoveries undoubtedly will be of deposits that do not outcrop. Prospecting for such deposits requires considerable digging.

Several important discoveries were made in 1934. One of these, the Rogers-Gentry gold mine at the edge of Antelope Valley in Los Angeles County, Calif., was found by an experienced prospector on an old patented homestead a number of miles from the nearest producing mine. The initial discovery at this mine was an iron-stained, decomposed, silicous limestone outcrop, with no vein structure evident at the surface, near a small, barren quartz outcrop and a water seep. Another discovery, the Silver Queen gold mine, in the same general region and near Mojave, Calif., was found by an experienced miner on an open fraction 400 by 1,400 feet in size between two old properties which were thought to have been worked out years ago. The Silver Queen discovery was made as the result of finding a single piece of float unlike any ore in the region. The vein did not outcrop; the discovery point was under 6 feet of cover.

To prospect for lode gold one should know first of all how to take care of himself in the hills or on the desert. He should be physically able to stand hard work and know how to use a pick and shovel. Most prospectors also have occasion to drill holes by hand and know how to use explosives. To prospect for lode gold intelligently one should be able to identify gold and the minerals usually associated with it, besides being able to distinguish one general class of rock from another.

Most prospectors work alone and are accustomed to solitude. As discoveries that can be sold for cash are few and far between prospectors must have some other resources for subsistence. Many prospectors work in the mines in the winter and prospect in the summer. Others do the assessment on claims for owners to earn enough money to buy supplies for pros-

pecting. In the old days many prospectors were grubstaked by merchants, individuals, groups of individuals, or companies, usually on a 50-50 basis. The practice now is followed less than formerly, but a professional prospector of good repute usually can get a backer.

Favorable Areas

Although the old saying that "Gold is where you find it" is quite true, the probability of finding gold in paying quantities will be increased greatly if prospecting is done in areas geologically favorable for the occurrence of gold. Regions in which gold is known to occur naturally are more favorable for prospecting than those where no gold has ever been produced.

The important known gold deposits in the United States occur in regions where intense igneous activity has occurred at some time. The most promising fields for finding new deposits of gold, therefore, should be in or near igneous rocks.[3] Not all igneous formations, however, are favorable for the deposition of gold. It probably would be a waste of time to prospect in dark lava flows. Large masses of granites or related coarsely grained crystalline igneous rocks are unlikely to contain gold deposits unless cut by dikes or other intrusions of finer-grained and usually light-colored igneous rocks, such as porphyry, rhyolite, or andesite.

Areas are favorable for prospecting where the principal rocks are granites (as suggested above), schists, slates, greenstones, or related rocks cut by later intrusives. Areas in which the principal rocks are the light-colored, finer-grained igneous rocks, especially if of several varieties, are also favorable.

One of the most favorable areas for the occurrence of gold is where the country rock is made up of surface flows, sills, dikes, and other intrusions of these light-colored igneous rocks.

Profitable gold deposits sometimes are found around the borders of great masses of granitic rocks, both in the granites and in the surrounding rocks but more often in the latter.

Large areas of sedimentary rocks,[4] such as shale, sandstone, and limestone, are unfavorable for prospecting unless the sediments are cut by the light-colored intrusions previously mentioned, and even where so cut the sedimentary areas seldom contain workable quantities of gold unless they have been metamorphosed (changed by pressure and heat) to slate, quartzite or marble.

Gold Lodes and Ore Shoots

Gold in paying quantities does not exist indiscriminately in country rock but where it has been deposited in definite zones usually termed "lodes." Solutions containing the gold have arisen from great depths and have been deposited by relief of pressure, cooling of the solutions, or other causes. For a lode deposit to have been formed there must therefore be some form of opening or zone of weakness through the rocks along which the solutions may rise. Earth movement or faulting commonly causes zones of weakness. Therefore, in prospecting it is well to keep a look-out for fracturing.

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3 According to Dana's Manual of Mineralogy, 14th ed., issued in 1929, p. 345, "Igneous rocks, as the name indicates, are those which have been formed by the cooling and consequent solidification of a once hot and fluid mass of rock material."

4 According to Dana, p. 350, "Sedimentary rocks are secondary in their origin, the materials of which they are composed having been derived from the decay and disintegration of some previously existing rock mass."

Parts of the lodes that contain gold in sufficient quantity to be ore (that is, material that can be mined at a profit) are called "ore shoots." Shoots seldom extend between walls but may be confined to a relatively narrow streak or streaks. Gold-ore shoots usually are relatively small. After a gold-bearing lode is located considerable work may be necessary to find an ore shoot; frequently the gold will not occur in sufficient quantity for any part of the lode to be worked at profit.

The simplest and most common form of gold lode is what is termed a "true fissure vein" by the miners. Fracturing, with or without faulting, has occurred in a relatively narrow zone with well-defined walls. The ore minerals have been deposited in this zone and may fill the space between walls completely. Usually, however, fractured country rock and, if the movement has been great, gangue or slickensides occupy part of the space.

Another type of lode is the shear zone. Here the walls usually are not well-defined. The ore-bearing solutions have deposited the gold and associated minerals in the cracks made by the fracturing. If present, ore shoots may occur anywhere in the fractured zone. Usually they overlap and occasionally may be parallel.

The contact between two different kind of rocks, especially an igneous rock and something else as schist, is generally a line of weakness. Ore-bearing solutions may have been able to rise along the places of weakness and form ore bodies. Such a lode is called a contact vein. Gold ore also may occur in bedded sedimentaries where a fissure cuts a contact, particularly between limestone and quartzite, where conditions are otherwise favorable geologically for the deposition of ore.

Searching for Gold Deposits

In looking for gold deposits vein or lode outcrops are sought and when found are examined for gold-bearing material. Portions of the veins have been eroded away; on steep hills part of the outcrops may have broken off and rolled down the hillside. Mineral-bearing fragments of vein material are called "float." Many deposits have been found by tracing float to its source. In prospecting, a lookout always is kept for such material. Float in the gravels of large streams may have come from many miles distant. In such instances the presence of the float indicates only that the gold-bearing material exists in the watershed above. Where float is found on a hillside the fragments are sought upward until no more are found. If the surface is covered with overburden trenching will be necessary to disclose the lead.

Lodes also may be located by panning loose material below for free gold. Placers are formed from disintegration of rock containing gold. During the ages gold lodes are eroded away at the surface, the gold-bearing rock is ground to powder, and the gold is concentrated in stream beds or desert deposits. The gold of rich placers, however, may have come from a multitude of narrow or low-grade streaks that could not be worked at a profit. The presence of placer gold in a stream bed indicates that the region above contains or has contained lode gold. In seeking for lodes in such a region the gravel of stream beds or debris of dry washes is panned to trace the gold to its source. If the gold suddenly plays out in the main watercourse attention then is directed to the side gulches, which in turn are followed up until no more placer gold is found. The debris on the mountainsides is then panned and the gold traced to its source. At this stage of prospecting float in the overburden may help in the search or be the key to the source of the gold.

Occasionally rich accumulations, called pockets, of free gold are found in the hillside debris. Especially in California pocket hunters have made a living by searching out these accumulations. The same procedure is followed whether the search is for a lode or a pocket. Valuable deposits in place have been found by pocket hunters.

As placer gold travels from its source it becomes flattened or rounded. Angular or jagged gold usually has not traveled far. The same is true of float. Well-rounded fragments of vein quartz may have traveled far, while angular pieces are not likely to have been transported a great distance. In flat, glaciated country float or free gold may have come from hundreds of miles away and may signify nothing as far as the immediate region is concerned.

Quartz, which usually is a constituent of gold ores, is hard and resistant to weathering. Furthermore, frequently the mineralization of a vein is accompanied by silicification of the vein filling and the immediate wall rock, which increases the resistance to weathering and erosion. Hence, a majority of veins containing gold ores outcrop above the surrounding surface. In flat regions, however, the outcrops may be covered with overburden brought down by floods. In some instances the vein may be badly fractured; any quartz present may be in narrow seams in a gangue of shattered country rock. When this is the case the vein at the surface may be softer than the adjoining wall rock and cause a depression. Trenching, therefore, is necessary to disclose the lode in place.

In searching for a hidden vein the following features which may be caused by the existence of a lode should be noted:[5]

1. A natural trench or ditch that does not run directly down the slope of the hill or mountain.
2. A sudden change of slope.
3. A sharp notch that crosses a ridge that has a rather uniform altitude on both sides of the notch.
4. Several springs in a line.
5. A sudden change in the kind or quantity of vegetation (may indicate a contact or, if the change in vegetation is found over a narrow strip of ground, a lode may be beneath).

Although many other possible causes may be responsible for these structural features some trenching would be justified if float was found immediately below and not above any particular one of them.

Iron sulphides, which frequently are associated with gold, oxidize to red or yellow oxides when exposed to the surface elements. The presence of a lode very often is disclosed by the stain of these iron minerals.

Present-day prospectors examine old cuts or other workings on abandoned claims. It is possible that with the increased price of gold and the improvements in metallurgy since the original work was done material passed up by the oldtimers may now be valuable.

With a few notable exceptions, the gold in lode deposits occurs as the native metal. At Cripple Creek and some of the other Colorado districts the gold is a constituent of telluride minerals; in general appearance these minerals resemble the iron sulphide minerals.

Gold and Associated Minerals

Gold can be identified readily by sight. It is the only soft, yellow substance with a metallic luster occurring in nature. It can be flattened easily without breaking and be cut or scratched readily with a knife. It is sometimes confused with pyrite, chalcopyrite, or other sulphide or with plates of yellow mica. Pyrite is too hard to be scratched with a knife, and sulphides that resemble gold crush into black powder. Yellow mica yields a white

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5 Butler, G. M., Some Hints on Prospecting for Gold; Arizona Lode Gold Mines and Gold Mining: Bull. Univ. of Arizona, Tucson, Ariz., vol. 6, p. 251.

powder when scratched with the point of a knife. When any doubt exists the suspected substance ordinarily is not gold.

The principal gangue mineral in gold deposits usually is quartz. This mineral is distributed widely in mineralized areas, but a very small percentage of it will be found to contain gold. Glassy or what is called "bull quartz" by the miners seldom if ever is gold-bearing. Massive quartz leads may be very persistent but generally are barren, except in some cases where secondary quartz with more of a porcelain appearance has been deposited. In the Mother Lode region of California the gold usually is associated with this secondary quartz.

With a few exceptions gold below the zone of oxidization generally is associated with or accompanied by sulphides. The principal sulphide ordinarily is pyrite; in some cases, however, chalcopyrite, arsenopyrite, or galena may be the important gold carrier. Gold may occur, however, in quartz without the associated sulphides or their oxidization products or in veins where quartz is not important. For example, in the Oatman (Ariz.) district all the gold is free, and the principal gangue mined is calcite.

Iron streaks or vugs (cavities, usually lined with a crystalline incrustation) in quartz-lead matter are promising places for native gold to occur. Frequently if present it can be seen by the naked eye or with a glass, therefore the prospector is on the look-out for iron-stained or honeycombed quartz. Outcrops, consisting mainly of iron oxides or lead matter heavily impregnated with iron (called gossan), when found in a mineralized region always should be tested for gold; the gossan may be at the top of copper or lead ore bodies with the latter two metals leached out. Sometimes the gossan carries paying amounts of gold.

Any outcrop or float of iron-stained, fractured, light-colored, igneous rock recemented with silica or showing evidence of silicification and banding should be investigated. The ore of the Silver Queen mine near Mojave, Calif., is of this latter type.

In glaciated regions and occasionally elsewhere sulphides occur at the surface. Moreover, float containing sulphides occasionally is found. Both outcrops and float usually are tested for gold by the prospector. Frequently the outcrop of a lead[6] is shown by green or blue copper stain. Should the original copper sulphide have been associated with gold the possibility of a deposit of gold ore exists.

Prospectors usually do not confine their efforts to the search for gold but will locate any deposit that promises to be of value, irrespective of the kind of contained mineral. To be present in sufficient quantities for the material to have value as an ore the base metals must occur in amounts readily discernible by the eye; the base metals, however, may have been removed from outcrops by leaching.

Sampling and Panning

As mentioned before, gold occasionally is visible in vugs or high-grade seams, but usually the gold in its ores is not visible either to the naked eye or with a glass. Rock suspected of containing gold may be tested by assaying or panning. Of course, the former method is to be preferred, but the cost ($1 to $1.50 per determination) precludes its general use by most prospectors. Some of the large mining and smelting companies, however, will assay free a reasonable number of samples sent in by bona-fide prospectors. In this way they may be the first to learn of new discoveries.

6 Commonly used as a synonym for ledge or lode. Many mining-location notices describe the locator's claim as extending a certain number of feet along and so many feet on each side of the "lode, lead, vein, or ledge." The word is pronounced "leed" and should not be confused with the metal lead.

Gold prospectors make a practice of panning (or horning) likely looking rock. The sample is first ground in a mortar or otherwise pounded into powder. A small frying pan from the 10-cent store appears to be preferred by most prospectors for panning rock samples. Although the greater reliability of relatively large samples is realized most prospectors when grinding the rock by hand and panning in the field use 1- or 2-ounce samples. In prospecting, the best-looking material is panned. After the rock has been shown to contain gold the value per ton should be ascertained by assaying. Samples for assaying should be cut over a definite width of the exposed vein.

A competent panner can estimate fairly closely the gold content of ore with which he is familiar. An expert panner with a 1-ounce sample can detect gold in rock that will assay only about 0.02 ounce of free gold per ton. A milligram of gold in an assay ton (29.168 grams) indicates 1 ounce of gold per ton of 2,000 pounds. An ounce avoirdupois is 28.350 grams.

Not all gold-bearing rock pans. Where the gold is associated with or contained in sulphides, grinding in a mortar may not liberate enough of the gold to be detected in the pan. In the United States, however, the gold in outcrops usually has been liberated by oxidization to such an extent that it can be panned.

In searching for gold most professional prospectors carry a mortar and a canteen of water. Likely looking rock is panned as found. By this procedure a load of rock is not accumulated, and many samples are tested that would not be carried to camp. Furthermore, there is no confusion regarding the location of the gold-bearing material, as often is the case when samples are accumulated.

Although an experienced man may identify gold tellurides in the ore or in the pan the sample should be assayed when their presence is suspected. Assays also are of course necessary to tell whether sulphides contain gold.

All major exposures of veins or other structures that appear favorable for the occurrence of gold should be sampled and assayed. No ore should be shipped without being assayed; almost invariably when this is done the shipper is disappointed. As mentioned above, samples should be cut across definite widths of the vein. Hand and grab samples of ore to be shipped are almost always high.

Surface Weathering

Weathering and leaching by surface solutions may remove the base metals from surface outcrops. Gold, however, is very resistant to leaching, and the weathering of the iron and associated minerals may increase the value per ton of surface ore; hence, it cannot be expected that the value of gold deposits will increase with depth; usually the contrary is true.

Prospecting on Patented Ground

Prospectors are reluctant to prospect on patented ground, as anything found would belong to the owners of the land. The author believes, however, that opportunities occur for finding new deposits on some of the thousands of idle patented mining claims held throughout the West. Many of these claims are held by estates. Even where the owners of idle claims would be willing to draw up papers to the effect that a discoverer of new ore would benefit from his findings, the average prospector would decline to go to this trouble and conduct his searches elsewhere.

Prospecting Outfits and Provisions

The outfit to be taken on a prospecting trip depends upon the mode of transportation, work contemplated, and the funds available. Enough equipment should be taken, but unnecessary articles make extra work. When a more or less permanent camp is established added equipment for personal comfort and efficiency can be obtained. Usually a cabin is built for a permanent camp.[7]

Transportation

An automobile is to be preferred for transportation if the region is one where it can be used. It has the advantage that a complete outfit can be carried and trips can be made out for supplies with relative ease. Most present-day prospectors use automobiles, especially in the desert regions. In mountainous regions away from roads the old stand-by, the burro, still finds favor. A prospector working alone generally uses two burros; occasionally, however, one animal suffices. A string of six or more burros will be used by a party; in this case a packer will be needed to look after the stock. About 150 pounds can be packed on each animal. A burro can live off the country and can go almost any place a man can get afoot. The principal objection to the use of burros is that they must be rounded up each day to keep them from wandering off beyond reach; a prospector will spend about a fourth of his working time chasing his burros. Mules or horses are used under some conditions but on the whole are less satisfactory for prospecting than burros. A horse cannot live off the country, and both mules and horses must be hobbled to keep them within reach.

Some prospectors prefer to get as near as possible to the area they wish to prospect by car and then carry supplies in on their backs to "spike" camps rather than bother with animals. Each year as more roads are built new country becomes accessible by car.

Camp Outfits

A roll of 3 or 4 blankets (the number depending upon the climate) in a canvas cover, a tent, a tight wooden box with a lid for storing food away from insects and rodents, and a canvas "war bag" for clothes usually make up the minimum camp outfit. A stove will be needed if prospecting is done in cold weather. A folding cot is desirable; in a permanent camp a bunk usually is built, as well as other needed furniture.

Tools

A full-sized ax and a good pocketknife are the first requirements for camping. A saw and a hammer with 2 or 3 pounds of assorted nails will be needed for fixing up a camp. A 50-foot length of 1/2-inch manila rope usually comes in handy. A miner's acetylene lamp provides a good light; a 5-pound can of carbide will last a camp all summer. A flashlight and a supply of batteries are conveniences that may be well worth their cost. A 2-quart canteen with a shoulder strap usually is needed for carrying drinking water or water for panning. A 2-gallon canteen and a 5- or 10-gallon water keg are necessary in some districts.

A pick, a long-handled, round-pointed shovel, a gold pan, and a prospector's pick are indispensable. If claims are to be staked a compass will be needed for running out the lines. A hand magnifying glass is a great help in identifying minerals. A mortar and pestle

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7 Gardner, E. D., and Johnson, C. H., Placer Mining in the Western United States: Part I - Prospecting Outfits and Provisions; Inf. Circ. 6786, Bureau of Mines, 1934, 73 pp.

a horn spoon, or a small pan will be needed for testing rock for free gold or other heavy minerals. A blowpipe outfit and determinative tables are of service to those who know how to use them. Bags for taking out samples usually are needed. Double paper bags with rubber rings cut from old automobile tubes for closing them permit large numbers of samples to be collected with little expense for bags.

A single-jack hammer with 2 or 3 moils will come in handy for taking samples and for loosening rock found in making cuts.

Some prospectors carry 1 or 2 sets of hand steel and several pounds of powder. A few rounds may be drilled and blasted before the steel has to be resharpened. If any extensive rockwork is to be done a forge and a set of blacksmith tools are necessary; usually these are brought in later.

Cooking Equipment

For a 1- or 2-man party a frying pan, a coffee pot, a large and a small stew pan or pot, and a Dutch oven are needed. A knife, fork, spoon, cup, and plate are required for each man. A few extra plates come in handy. A good butcher knife, a water pail, a can opener, and a few tea towels complete the outfit. Other dishes can be taken according to personal preferences.

Provisions

The variety of food taken on prospecting trips depends upon the method of transportation and the prospector's pocketbook. If the supplies are to be packed on animals bulky foods, such as potatoes and canned articles, are omitted. If there is need for economy in making purchases the list will consist mostly of dried staples and vegetables, if available locally.

Bacon, flour, beans, oatmeal, dried or canned fruit, coffee, syrup for hot cakes, and sugar and canned milk for the coffee are the stand-bys in prospectors' camps. As funds get low more beans and less bacon are eaten, and canned fruit is omitted. Canned tomatoes are in common use; they are cheap and supply needed food elements not contained in dry staples (for example, they help to prevent scurvy). Where available locally Irish potatoes, onions, and other vegetables are eaten. Fresh meat is not used much in camps in summer on account of the difficulty of keeping it.

A proper balance should be made in compiling a "grub" list so that needed items will not run short. Everyone prefers certain articles of food, and these likes should be followed as much as practicable. It has been found by experience, however, that fancy groceries are the ones left over, and the first supplies to be used are bacon, potatoes, and flour. Plain, wholesome fare seems to be preferred in camp, especially where hard work is done.

The following weekly allowance of food for one person to give a balanced diet is condensed from suggestions made by Doctor Smith:[8] Three 1-pound cans evaporated milk; 2 pounds potatoes; 4 pounds onions, cabbage, beets, or other vegetables; 3 pounds citrus fruits, 6 pounds fresh apples, or equivalent dried prunes, apricots, etc.; 3 pounds dried beans; 6 to 8 pounds cereals, whole-wheat flour or bread, rolled oats, shredded wheat, etc.; 2 1/2 pounds dried meat, bacon, ham, or cheese (fresh meat or eggs may be substituted if available); 3 pounds sugar; 1 pound coffee; 1/4 pound salt; 1/2 pound butter; and baking powder.

The cost of provisions for prospecting in the West will average about 50 cents per day per man. Many prospectors live in the hills when short of funds on as little as 25 cents per day each; they are not well-nourished, however, and do not have a balanced diet.

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8 Smith, Margaret Cammack, Food Suggestions for Prospectors; Arizona Gold Placers and Placering: Bull. Univ. of Arizona, vol. 3, no. 1, Jan. 1, 1932, pp. 96-98.

In many districts of the Southwest water must be carried. The quantity required depends upon the time of year and the amount of work done by the miner. Men working where temperatures range from 100 to 110° drink 2 gallons or more of water per day; under such conditions a 10-gallon tank would last one man 3 days, allowing for cooking but not for the radiator of a car. In cooler weather a 10-gallon tank should last one man a week or 10 days.

Clothing

The most important item of clothing is a pair of stout, thick-soled shoes of good quality, preferably hobnailed. If an extensive trip is planned a second pair may be needed. Other clothing can be patched, but when a prospector's shoes go to pieces his trip is ended. A pair of rubber boots will prove a comfort if much placering is done.

Woolen socks to wear under the heavy shoes help to prevent blisters; several pairs may be worn out in a season.

Other clothes are chosen for the climate and service. A leather jacket is very serviceable and comfortable in cool weather, or a sheepskin coat may be needed when it gets colder. Many prospectors in mountainous regions wear flannel shirts and woolen underwear. Overalls are a common garb.

A complete change of clothing should be taken on all but the shortest trips to permit changing into dry clothing after being caught out in the rain or working in water all day.

First-Aid Supplies

As prospectors are likely to be away from medical aid, some medical and first-aid supplies should be taken along. These should consist of a laxative (castor oil or salts), iodine or mercurochrome to disinfect cuts or bruises, and a first-aid kit. A snake-bite kit may also prove invaluable.

LOCATING CLAIMS ON THE PUBLIC DOMAIN

By Fred W. Johnson[9]

CONTENTS

INTRODUCTION

In addition to a knowledge of ore minerals and their identification and occurrence, methods of sampling and prospecting, and supplies and equipment required, the prospector must have a general knowledge of how and where mining claims can be located on the public domain. The following information about mining laws has been compiled to meet this need, and every reasonable care has been taken to make it accurate and reliable at the time it was written (January 1936). The reader is warned, however, that changes are made from time to time in the laws and regulations covering the location and patenting of mining claims and that the Bureau of Mines is not the authority on the subject. <u>If specific advice is desired as to any provision of the United States mining laws, inquiry should be directed to the Commissioner of the General Land Office, Washington, D.C. Inquiries concerning the status of any tract of land should be made to the Register of the U.S. Land Office of the district in which the land is situated.</u>

Lands to Which Mining Laws Apply

The laws (act of May 10, 1872, and amendments) pertaining to acquiring mining claims on vacant public lands apply to Arizona, Arkansas, California, Colorado, Florida, Idaho,

9 Commissioner of the General Land Office.

Louisiana, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming, and to Alaska. Lands containing vein or lode deposits can be located and patented where vacant and unappropriated in the public domain, in National forests in the States named, in patented and unpatented stock-raising homesteads, in other agricultural entries not perfected or patented where prospecting can be done peaceably, and in railroad grants that have not been patented. Public lands temporarily withdrawn from settlement, location, sale, or entry and reserved for classification or other public purposes are, as a rule, open at all times to exploration for metalliferous minerals and to location and purchase under the mining laws. However, lands withdrawn for reservoir sites and certain other purposes are not subject to mining location; neither are those included in power sites unless restored under the Federal water power act. One desiring to prospect any particular lands should ascertain from the Register of the U.S. Land Office whether or not they are withdrawn or reserved from mining location. Placer claims generally can be located on lands having the same status as lands subject to location if containing vein or lode deposits, except that deposits of coal, oil, gas, oil shale, sodium, phosphate, potash, and sulphur (in Louisiana and New Mexico) belonging to the United States can be acquired only under the mineral leasing laws and are not subject to location under the United States mining laws.

Mining claims cannot be filed upon patented land except where the minerals have been reserved to the United States, on military reservations, or in National parks or monuments (except Mt. McKinley National Park in Alaska and Death Valley National Monument in California). Lands below high tide or the beds of navigable lakes and rivers are not subject to mineral location.

New lode locations can be made over abandoned earlier locations.

Public lands valuable for minerals are not subject to entry or patent under homestead or other nonmineral laws, except under certain laws that provide for patent with reservation of the minerals. Stock-raising homestead entries may include mineral lands not embraced in valid mining claims and may be patented with reservation of all minerals in the land to the United States. Lands entered or patented under this law may be prospected for minerals and, upon discovery, located as mining claims; but the miner's rights are restricted to the minerals in the land and the use of so much of the surface as necessary to mine and remove the minerals.

A lode or vein known to exist in a placer claim prior to the date of the filing of the application for placer patent can be located in the same manner as on vacant public land, but such location is limited to 25 feet on each side of the vein or lode at the surface. A lode deposit cannot be held under a placer location, but once a placer claim is patented the owner owns and may mine all lodes not known to exist at the time the application for placer patent is filed.

Mineral Discovery

The first requirement for locating a lode claim is to make a mineral discovery. This should consist of a "vein", "lode", "ledge", or "crevice" containing valuable "mineral" in place. It is not required that the mineral showing be of sufficient size or grade to be mined at a profit. The finding of float on a lode claim, even if present in sufficient quantity that it may be collected at a profit, does not constitute a mineral discovery. Although technically a valid lode claim cannot be located until actual valuable mineral has been found in place, it is common custom to post a location notice on open ground where hidden leads are being sought by excavating. If valuable mineral is found by this work, the prospector is afforded some protection by having the location posted should an effort be made to "jump" the ground.

Location of Lode Claims

Mining locations may be made by citizens of the United States, by those who have declared their intention to become citizens, by an association of qualified persons, or by a domestic corporation. Locations can be made by minors who have reached the age of discretion, and without regard to the sex or residence of the locator. A locator may include as colocators other qualified persons who may or may not have seen the ground; moreover, a person may make valid locations as agent for other qualified parties.

No limit is placed by the Federal statutes on the number of locations that may be made by an individual or a company. Both lode and placer claims may be amended and the boundaries changed at any time, provided that such changes do not interfere with the rights of others.

A location notice must contain the names of the locator or locators, the date of location, and a description of the claim by reference to some natural object or permanent monument that will identify it. Lode claims must be marked distinctly on the ground so that their boundaries can be traced readily. State laws define how the location notice must be posted, what the size of the discovery cut or shaft shall be, and how the claim boundaries shall be marked. The location notice should be filed as required by the State laws.

Lode claims are limited to 1,500 feet in length and 300 feet on each side of the lode or vein at the surface. The maximum size of a claim is a parallelogram 600 by 1,500 feet (20.661 acres). The end lines of the claim must be parallel. A claim does not need to be of full size or to be rectangular. If a vein on which a claim is staked curves, the side lines of the claim may be broken to make the location fit the vein. A full-sized claim may be staked so as to embrace two or more noncontiguous fractions of open ground, and a discovery on one of such fractions is sufficient to validate the entire location.

Assessment Work

To hold the possessive title to a mining claim, not less than $100 worth of work must be done or an equivalent value of improvements made upon or for the benefit of each claim each year, regardless of its size. Where a number of contiguous claims are held in common, the aggregate expenditures for the group may be made on one claim, provided such expenditure tends to benefit or develop each claim of the group. Locations connecting only at the corners are held to be noncontiguous. The period within which the annual work must be done begins at noon of July 1 succeeding the date of location. Failure to do the annual assessment work will subject a claim to location by others unless work is resumed before such relocation. It has been held that a claim is not subject to relocation if work is being done on the ground at the end of the required period. In other words, if work is begun by noon of July 1, 1930, on a claim located in September 1928, and diligently carried on thereafter to completion, it is not subject to relocation. Additional work would be required for the period beginning July 1, 1930. Annual expenditure is not required after entry is made at the Land Office for patent.

Should the annual assessment work not be done on a claim for one or more years, the location will still be valid if work is resumed on the ground, provided there has been no relocation by another prior to such resumption of work. Most States have provided for filing proofs of labor for the annual assessment work.

Where one of several locators fails to contribute his share of the required expenditures made for the benefit of a claim, the co-owners, at the expiration of the period, may give notice personally, in writing, or by advertising in the newspaper published nearest the claim at least once a week for 90 days; if upon the expiration of 90 days after the personal notice or upon the expiration of 180 days after the first newspaper notice the delinquent

co-owner shall have failed to contribute his proportion of such expenditures or improvements, his interest in the claim passes by law to his co-owners who have made the required expenditures.

Suspension of Assessment Work

Congress suspended the assessment work on all claims for the assessment year ended July 1, 1932. All claim owners who were exempt from the payment of Federal income tax were relieved from making the required annual expenditure for the years ended July 1, 1933, July 1, 1934, and July 1, 1935, subject to filing and recording of notice of intention to hold the claims. During 1934-35, the suspension applied to only 6 lode claims, or 120 acres of placer ground, held by an individual or 12 lode claims, or 240 acres of placer ground, held by a partnership, association, or corporation.

Indian Reservation

The Secretary of the Interior has been authorized by Congress (act of June 30, 1919, and amendment of March 3, 1921) to lease unallotted lands on Indian reservations for mining purposes in Arizona, California, Idaho, Montana, New Mexico, Nevada, Oregon, Washington, and Wyoming. After declaration by the Secretary that the lands are subject to lease, claims may be located as on the public domain; a duplicate of the location notice must be filed with the superintendent in charge of the reservation within 60 days. The locator has 1 year's preference right to apply for a lease through the reservation superintendent to the Secretary of the Interior. Leases are for 20 years, with provision for 10-year renewals.

In other States, unallotted lands not needed for allotment or agriculture may be leased for mining purposes for not more than 10 years.

Lands in the Papago Indian Reservation, in Arizona, are subject to location and patent under the provisions of the United States mining laws. Locators are required to pay a rental of not less than 5 cents per acre to the Papago Tribe, and, in event patent is desired, 1 dollar per acre; and the amount of any damages for loss of improvements made by the Indians must be paid, the damages to be determined by the Secretary of the Interior.[10]

National Forests in Middle Atlantic States

As stated before, mineral lands in national forests in the public land States may be entered as on the public domain. In the Middle Atlantic States (where the Federal mining laws do not apply) special regulations have been promulgated by the Department of Agriculture permitting prospecting, development, and utilization of the mineral resources on national forest lands.

Prospecting may be carried on without a permit, but no extensive excavations can be made or structures erected without a permit. For a fee of $5.00 exclusive prospecting permits, one to a person, will be issued to qualified persons to explore a specified area not to exceed 100 acres. Permits may be renewed.

Upon application, after the discovery of valuable mineral deposits, a mining permit will be granted for 5 to 20 years at a rental of not less than $1.00 per acre per year, and not less than $2.00 for any permit. In addition, a royalty of 2 to 8 percent of the value of the minerals mined will be charged. Rules are laid down by the Forest Service as to cutting timber and how the mining work shall be conducted.

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10 See Circular 1347, General Land Office, February 27, 1935.

State Lands

When statehood was conferred upon the Western States, Congress granted to them sections 16 and 36 of each township for school, road-building, or other purposes. Sections 2 and 32 also were granted to Arizona, New Mexico, and Utah. Some special land grants also have been made to most of the Western States. By the terms of the original grant, the States were required to take lieu selections for lands already occupied at the time of the grant or known to be mineral at the time the land was surveyed. Congress, however, by the act of January 25, 1927, granted the States the mineral school sections subject to existing claims.

Most of the mining States provide for leasing minerals found on State land, but some provide for mining locations. After discovery, application for a prospecting or mining lease should be made to the authority having charge of State lands. Regulations on the granting of prospecting or mining leases vary in different States.

Mining Claims on Stock-Raising Homesteads

Patents to stock-raising or grazing homesteads reserve all minerals to the Government. Any qualified locator may go upon the lands entered or patented under the stock-raising homestead act to prospect for minerals, provided he does not damage the permanent improvements of the entryman; he also is liable for all damage he does to crops. (See General Land Office Circular No. 523.)

Anyone who has acquired the right from the United States to mine the minerals may reenter and occupy as much of the surface as is required for mining purposes (1) by obtaining a written consent or waiver from the homesteader; (2) by payment for crops or tangible improvements to the owner under agreement; (3) by posting a bond of at least $1,000 to cover any damages that might be awarded by a court of competent jurisdiction. The bond must be filed with and approved by the register of the Land Office. The Land Office will allow mineral applications on stock-raising homesteads, whether patented or held under entry, and patent will be issued in the regular manner except that it will contain the notation that the land is subject to occupancy and used in accordance with the act of December 29, 1916.

State Mining Laws

By the act of May 10, 1872, Congress authorized State and Territorial legislatures to pass laws regulating the location and holding of mining claims on the public domain. The States in which the mining laws apply have made regulations in addition to those passed by Congress regarding mining claims. By the act of May 17, 1884, the Federal mining laws were extended to Alaska.

Size of Claims

Except for South Dakota and North Dakota, the maximum size of lode claims prescribed by Congress (600 by 1,500 feet) is permitted by State laws. In South Dakota the claims are full width, except where a county at a general election may determine on a narrower width, but not less than 25 feet on each side of the center line. In North Dakota the standard lode claim is 150 feet on each side of the center line, except that by the same procedure as above the width may be increased to 300 feet on each side of the center line. In Colorado, claims were limited to 75 feet in Gilpin, Clear Creek, Boulder, and Summit Counties on each side of the center line, and to 150 feet on each side of the vein in the other counties of the State before 1921, at which time the law was amended to allow full-size claims.

Location Notices

All of the States that have enacted laws pertaining to the location of mining claims require location notices to be posted at the point of discovery, except in New Mexico, where the law provides that the notice shall be posted at a conspicuous place on the claim, and Oregon, where the law merely provides that the notice must be posted on the claim. The United States mining laws require that a location notice for a lode claim shall contain (1) the name of the claim, (2) the name of the locator or locators, (3) the date of location, and (4) such a description of the claim or claims located, by reference to some natural object or permanent monument, as will identify the claim. In addition, the laws of Arizona, California, Idaho, Nevada, Oregon, South Dakota, Utah, and Wyoming require that (1) the general course of the vein as nearly as can be determined, (2) the distance claimed on each side of the center line or discovery cut, i. e., the width of the claim, and (3) the distance claimed both ways along the lode from the point of discovery be shown either in the location notice posted on the claim or in the certificate of location filed for record. Also, the Idaho laws require that the location notice contain the name of the mining district, county, and State. In Alaska, in addition to the Federal requirements, a lode location notice must state the number of feet claimed along the vein each way from the point of discovery and the width on each side of the center line; in Colorado the notice must state the number of feet claimed on each side of the discovery shaft and the general course of the lode as near as can be determined; and in Montana the notice must give the approximate dimensions of the claim.

In most mining districts blank forms of location notices can be purchased from printing establishments or at stores handling stationery. These forms are a convenience in making locations and show the requirements to be followed in the particular State.

Filing Certificate of Location

All Western States require that a copy of the location notice or a certificate of location be filed for record. Thirty days from the date of making discovery or posting of location notice is allowed for filing lode claims in California and Utah; 60 days in Montana, North Dakota, Oregon, South Dakota, and Wyoming; 90 days in Alaska, Arizona, Colorado, Idaho, Nevada, New Mexico, and Washington. In Arizona, California, Colorado, Idaho, and North Dakota location notices or certificates and proofs of annual labor are filed with the county recorder; in Alaska, with the district mining recorder; in Montana, New Mexico, and Wyoming, with the county clerk; in South Dakota, with the recorder of deeds; and in Washington, with the county auditor. In Nevada and Utah notices are filed in duplicate with the district mining recorder if there is one; otherwise, with the county recorder. In Oregon the notices are filed with the recorder of conveyances, if there is one; otherwise, with the county recorder. Arkansas does not require the filing of notices for record, but provision is made for such filing with the county recorder if the mining claimant so desires. The cost of filing notices for record varies from $1.00 to $2.00. In Arizona and New Mexico the notice filed for record must be a copy of the location notice, and in Idaho and Utah the notice filed must be a "substantial" copy of the location notice. In Montana the notice filed must be sworn to, and in Oregon an affidavit must be attached stating that the discovery work has been performed. In Wyoming the notice filed for record must give the location of the claim by reference to section or quarter-section corners, if the claim is on surveyed land.

Marking Boundaries

In all Western States the boundaries of lode locations must be marked before the location notice is filed for record. In Montana and Oregon the boundaries must be marked within 30 days; in Idaho, 10 days; and in Nevada, 90 days after the location notice is posted.

In Utah there are no State regulations as to marking corners, except that they shall be marked distinctly. In Idaho, Montana, and Washington the corners or angles of the claims (four or more corners) shall be marked with substantial monuments. In Alaska, Arizona, California, Nevada, Oregon, and Wyoming each corner and center-end lines of lode claims shall be so marked. In North Dakota and South Dakota each of the four corners, the center-end line, and the center-side lines of lode claims shall be marked and the corners of placer claims by monuments. In Alaska and Washington the claim boundaries must be marked by cutting brush or blazing trees, if claims are covered by such growth. In Colorado the corners of the claim and the center-side lines must be marked.

In Alaska the claim corners of lode claims must be marked by posts at least 3 inches in diameter and 3 feet above ground or by mounds of earth or stone 3 feet high and 3 feet in diameter. The corners must be marked with the name of the claim, the number or position of the corner, and the direction of the boundary lines. In Arizona the monuments must consist of a 4-foot post or a mound of stone 3 feet high. In Colorado and Idaho when posts or trees are used they must be marked, and in Idaho if posts are used they must be at least 4 inches square. In Montana a corner can consist of an 8-inch tree blazed on four sides, a 4-inch square post 4-1/2 feet long surrounded by a mound 4 feet in diameter and 2 feet high, or a square stump with mound, a stone 6 by 18 inches two-thirds in the ground with a mound 4 by 2 feet nearby, or a boulder 3 feet above ground, and each corner is to be marked. Requirements for corners in Nevada are similar to those in Montana. In North Dakota and South Dakota corners are to consist of substantial posts hewed or glazed on the side or sides facing the claim and marked with the name of the claim and the corner. In Oregon the corners must consist of posts at least 4 inches square and 3 feet high or mounds at least 2 feet high; in Washington similar monuments are required, except that mounds must be 3 feet high. In Wyoming substantial corners of stone or posts sunk into the ground are required; they must be marked on the side or sides that face the claim.

Discovery Excavations

No discovery shafts or excavations are required on lode-mining claims in Utah. Alaska, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, South Dakota, Washington, and Wyoming require that a 10-foot shaft shall be excavated or an equivalent excavation made. In Alaska, the shaft or its equivalent shall be made within one year of the date of location; in California, Nevada, and New Mexico within 90 days; in Colorado, Idaho, Montana, and Oregon within 60 days; in South Dakota, Washington, and Wyoming before the location notice or certificate is filed for record. In North Dakota sufficient excavation must be made to show a well-defined vein or lode before filing the location notice. In Arizona and Nevada the shaft must be at least 4 by 6 feet in section; in Idaho it must be 16 square feet in cross-section or contain 160 cubic feet; in Montana it must contain 150 cubic feet, part of which can be elsewhere on the claim, but 75 cubic feet must be excavated at the point of discovery.

Proofs of Labor

In Alaska, Arizona, California, Idaho, Nevada, New Mexico, Utah, Washington, and Wyoming proof of labor, showing that the annual assessment work has been done on claims, is

required to be filed. Such proofs should be sworn to and should be filed within 90 days after the first day of July in Alaska and Arizona; within 60 days after the first day of July in Idaho, New Mexico, and Wyoming; within 30 days after the first day of July in California and Washington; within 60 days after the work is done in Nevada and Wyoming; within 30 days after the work is done in Utah; and within 20 days after the work is done in Montana. In Arkansas, Florida, Louisiana, Nebraska, North Dakota, Oregon, and South Dakota it is not necessary to file proofs of labor.

Status of Unpatented Lode Claims

A valid lode claim held by right of location may be sold or leased like any other real estate. Ores may be mined and sold from claims held under location, as from patented claims. Patented and unpatented lode claims are taxable, as are buildings and their contents placed upon them.

Timber Rights

Timber and stone on national forests may be used free of charge by bonafide settlers, miners, residents, and prospectors for firewood, fencing, building, mining, prospecting, and domestic purposes under regulations set forth by the Forest Service. Timber on unpatented claims may be used for mining purposes but not sold.

Procedure to Obtain Patent to Lode Claims

Valid locations or groups of locations on which not less than $500 has been expended for the benefit of each claim may be patented. Proceedings for patent are instituted in the district Land Office. The claims or claim must be surveyed by a U.S. mineral surveyor; the application for a survey is made to the public survey office. Notice of the application is required to be posted on the land before the application is filed and published by the register of the Land Office after the application is filed. Information as to patent procedure can be obtained from the register of the local land office or from the General Land Office in Washington.

Adverse Claims

An adverse claim must be filed under oath with the register of the Land Office before the period of advertising expires. The adverse claim must set forth fully the nature and extent of the interference or conflict, whether the adverse party claims as a purchaser or as a locator. If the former, a duly certified copy of the original location notice, the original conveyance, or an abstract of title from the office of the proper recorder should be furnished; if verbal, the circumstances should be narrated. If as a locator, he must file a duly certified copy of the location notice from the office of the proper recorder.

The adverse claimant must also file a plat showing his entire claim and its relative position with regard to the one that he claims conflicts, unless the claims of both parties are located by legal subdivisions.

Upon filing the adverse claim, the register of the Land Office will give notice to the parties that adverse claim has been filed, informing them that the adverse claimant will be required, within 30 days from the date of such filing, to begin proceedings in a court of competent jurisdiction to determine the question of right of possession and to prosecute the action with reasonable diligence to final judgment, and that, should he fail to do so, his adverse claim will be considered waived and the application for patent will be allowed to proceed on its merits.

After this report has served your purpose and if you have no further need for it, please return it to the Bureau of Mines. The use of this mailing label to do so will be official business and no postage stamps will be required.

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

LIST OF DEVICES FOR RESPIRATORY PROTECTION APPROVED BY THE U. S. BUREAU OF MINES[1]

By W. P. Yant[2]

Publication of lists of the devices for giving respiratory protection which have been approved by the U. S. Bureau of Mines is made periodically for the purpose of aiding consumers in procuring equipment.[3,4] The last published list, approved to May 1, 1933, appeared in the Journal of Industrial Hygiene,[5] accompanied by a discussion of the purpose, operating procedure, and general requirements of the approval system and by a selected list of the Bureau's publications which deal with respiratory protection. In previous listings the kinds of devices approved were self-contained oxygen breathing apparatus, canister-type gas masks, and hose masks. Since that date a schedule of requirements for filter-type dust, fume, and mist respirators has been issued, and devices of that kind have been tested and approved.

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1 - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6845."
2 - Supervising chemist, gas section, and supervising engineer, Pittsburgh Experiment Station, U. S. Bureau of Mines.
3 - Bureau of Mines, List of Permissible Self-Contained Oxygen Breathing Apparatus, Gas Masks, and Hose Masks: Inf. Circ. 6362, 1930, 2 pp.
4 - Bureau of Mines, List of Permissible Self-Contained Oxygen Breathing Apparatus, Gas Masks, and Hose Masks: Inf. Circ. 6494, 1931, 3 pp.
5 - Yant, W. P., Bureau of Mines Approved Devices for Respiratory Protection: Jour. Ind. Hygiene, vol. 15, 1933, pp. 473-480.

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[illegible]

The schedules of requirements and tests which the devices must meet in order to obtain approval are published[6,7,8,9] by the Bureau of Mines and are available to the public. It is pertinent to mention that consideration is being given to the preparation of a schedule of requirements for fresh-air supply devices of the types commonly known as positive-pressure respirators, air-line respirators, sand-blast helmets, and hoods.

List of Approved Devices
March 15, 1935

The following is a list of all devices for giving respiratory protection which had official certification of approval by the U. S. Bureau of Mines on March 15, 1935. The equipment listed and the manufacturers thereof have met all of the requirements and passed the tests for safety, practicability, and efficiency required at the time approval was granted, and which are described in detail in the schedules cited.

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6 - Bureau of Mines, Procedure for Establishing a List of Permissible Self-Contained Mine Rescue Breathing-Apparatus. Fees, Character of Tests, and Conditions Under Which Mine Rescue Breathing Apparatus Will be Tested: Sched. 13, Mar. 5, 1919, 13 pp. Sched. 13A (revision of Schedule 13), January 21, 1930, 12 pp.

7 - Bureau of Mines, Procedure for Establishing a List of Permissible Gas Masks. Fees, Character of Tests, and Conditions Under Which Gas Masks Will be Tested: Sched. 14, May 22, 1919, 13 pp. Supplement to Sched. 14, Jan. 6, 1920, 4 pp.
Sched. 14A (revision of Schedule 14), Aug. 25, 1923, 15 pp. Sched. 14B (revision of Sched. 14A) Aug. 7, 1930, 13 pp. Sched. 14C (revision of Sched. 14B), Aug. 20, 1934, 17 pp.

8 - Bureau of Mines, Procedure for Testing Hose Masks for Permissibility: Sched. 19, Apr. 28, 1927, 8 pp. Supplement to Sched. 19, Aug. 20, 1934, 3 pp.

9 - Bureau of Mines, Procedure for Testing Filter-Type Dust, Fume, and Mist Respirators for Permissibility: Sched. 21, Aug. 20, 1934, 14 pp.

Self-Contained Oxygen Breathing-Apparatus
Approved Under Schedules 13 and 13A

1. Gibbs mine rescue breathing-apparatus. Approval No. 1300, issued to Mine Safety Appliances Co., Braddock, Thomas and Meade Streets, Pittsburgh, Pa., January 15, 1920.

2. Paul mine rescue breathing-apparatus. Approval No. 1301, originally issued to American Atmos Corporation, 909 Hay Street, Wilkinsburg, Pa., January 15, 1920. Later transferred to Mine Safety Appliances Co.[a]

3. Fleuss-Davis Proto mine rescue breathing-apparatus. Approval No. BM-1302, issued to Siebe, Gorman & Co. (Ltd.), London, England, February 7, 1924.

4. McCaa mine rescue breathing-apparatus. Approval No. 1303, issued to Mine Safety Appliances Co.,[a] August 31, 1925.

5. Draeger mine rescue breathing-apparatus (1924 type). Approval No. 1304, issued to Draegerwork, Lübeck, Germany, August 1, 1929.

6. McCaa half-hour oxygen breathing-apparatus. Approval No. 1305, issued to Mine Safety Appliances Co.,[a] April 1, 1931.

Gas Masks Approved Under Schedule 14, 14A, and 14B

Type A: Acid Gas Masks

1. M.S.A. hydrocyanic acid gas mask. Approvals No. 1413, regular size canister, and 1414, supersize canister, issued to Mine Safety Appliances Co.,[a] December 9, 1933.

Type AB: Acid Gas and Organic Vapor Masks

1. M.S.A. acid gas and organic vapor mask. Approval No. 1409, issued to Mine Safety Appliances Co.,[a] January 23, 1930.

2. M.S.A. hydrogen sulphide and petroleum-vapor mask. Approval No. 1410, issued to Mine Safety Appliances Co.,[a] July 16, 1930.

3. Davis acid gas and organic vapor mask. Approval No. 1411, issued to Davis Emergency Equipment Co., Inc., 55 Van Dam Street, New York, N. Y., January 19, 1931.

4. M.S.A. hydrogen sulphide and petroleum-vapor mask. Approval No. 1412, issued to Mine Safety Appliances Co.,[a] September 14, 1931.

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a See previous listing of company for complete address.

Type C: Ammonia Gas Masks

1. M.S.A. ammonia gas mask. Approval No. 1401, issued to Mine Safety Appliances Co.,[a] April 10, 1920.

2. G.M.D. ammonia gas mask. Approval No. 1404, issued to Mine Safety Appliances Co.,[a] March 10, 1926.

3. LaFrance ammonia gas mask. Approval No. 1401, issued to American-LaFrance and Foamite Industries, Inc., Elmira, New York, June 23, 1927.

4. G.M.D. ammonia gas mask. Approval 1406, issued to Mine Safety Appliances Co.,[a] February 14, 1928.

5. Davis ammonia gas mask. Approval No. 1408, originally issued to Bullard-Davis, Inc., December 19, 1928, later transferred to Davis Emergency Equipment Co., Inc.[a]

6. LaFrance ammonia gas mask. Approval No. 1408, issued to American-LaFrance and Foamite Industries, Inc., Elmira, N. Y., November 18, 1930.

Type D: Carbon Monoxide

1. M.S.A. self-rescuer. Approval No. 1402, issued to Mine Safety Appliances Co.,[a] March 6, 1924.

Type N; Gas Masks for Protection Against Acid Gases, Organic Vapors, Carbon Monoxide, Ammonia, Smokes, Dusts, and Mists

1. All-Service gas mask. Approval No. 1403, issued to Mine Safety Appliances Co.,[a] July 1, 1925.

2. All-Service gas mask. Approval No. 1405, issued to Mine Safety Appliances Co.,[a] August 24, 1928.

Hose Masks Approved Under Schedule 19 and Supplement to Schedule 19

1. M.S.A. combination hose mask. Approval No. 1901, issued to Mine Safety Appliances Co.,[a] May 29, 1929.

2. Davis hose mask. Approval No. 1902, issued to Davis Emergency Equipment Co., Inc.,[a] March 30, 1931.

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a See previous listing of company for complete address.

3. Bullard hose mask. Approval No. 1903, issued to E. D. Bullard Co., 275 Eighth Street, San Francisco, Cal., April 14, 1933.

4. Davis hose mask with Davis-Root positive pressure blower (approved for two lines of hose). Approval No. 1904, issued to Davis Emergency Equipment Co., Inc.,[a] October 29, 1934.

5. M-S-A combination hose mask (approved for two lines of hose). Approval No. 1905, issued to Mine Safety Appliances Co.,[a] January 7, 1935.

Filter-Type Dust, Fume, and Mist Respirators Approved Under Schedule 21

Type-A Respirators: For Protection Against Pneumoconiosis-Producing or Nuisance Dusts, as Quartz, Asbestos, Iron Ores, Cement, Limestone, Gypsum, Coal, Coke, Charcoal, Wood, Cellulose, Flour, and Aluminum

1. M-S-A Comfo Respirator. Approval No. 2101, issued to Mine Safety Appliances Co.,[a] January 7, 1935.

2. Willson Bag Respirator No. 300. Approval No. 2102, issued to Willson Products, Inc., Reading, Pa., January 21, 1935.

3. Willson Bag Respirator No. 400. Approval No. 2103, issued to Willson Products, Inc.,[a] January 21, 1935.

4. Pulmosan M-15 Pouch-type Filter Respirator. Approval No. 2104, issued to Pulmosan Safety Equipment Corporation, 176 Johnson Street, Brooklyn, N. Y., February 9, 1935.

5. Biever Respirator. Approval No. 2105, issued to Standard Safety Equipment Co., 75 East Wacker Drive, Chicago, Ill., March 5, 1935.

Type-A respirators are not approved for protection against poisoning by breathing dusts whose main harmful constituents are metals or their compounds, such as antimony, arsenic, cadmium, chromium, lead, manganese, mercury, selenium, tellurium, thallium, uranium, and vanadium; or protection against harmful smokes and fumes. Respirators for protection against these forms of particulate matter require special approval. Type-B respirators are for protection against fumes and smokes, and Type-C are for protection against mists, as chromic acid mist. No respirators of either of the special types mentioned (Type-B and Type-C) have been tested and approved.

Identification of Approved Devices

All devices which are marketed under the provisions of the U. S. Bureau of Mines approval system must bear, either on the package or affixed to the device, an approval label on which is reproduced the seal of the Bureau of

a See previous listing of company for complete address.

Mines, the approval number, and the name of the manufacturer to whom the approval is issued. Self-contained oxygen breathing-apparatuses bear a plate affixed to the apparatus. Canister-type gas masks bear a label on the case and on each canister, and the approval number is stamped on the facepiece and harness, such as BM-1400. Hose mask cases bear an approval label, and the approval number is stamped on the facepiece, harness, and individual lengths of hose. The cases of filter-type respirators and containers for replacement filter units bear the approval label, and the approval number is stamped on the facepiece and each filter unit. These filter units also bear a marking which designates the class of particulate matter for which they are approved, as Type-A, Type-B, and Type-C.

These markings are placed on the devices for the purpose of providing purchasers and users with a means for identifying approved devices and for procuring approved parts when making repairs and replacements. The marking also obligates the manufacturer to maintain the quality of the product and to see that each device in all its parts is constructed in exact accordance with specifications of the device that the Bureau examined and approved. Any device that exhibits changes in design or includes any parts that were not in the device approved, regardless of whether the change is made by the manufacturer or the consumer, is not permissible and must not bear the Bureau of Mines approval label.

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I. C. 6846

June 1935

DEPARTMENT OF THE INTERIOR

UNITED STATES BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

PLACER-MINING METHODS OF E. T. FISHER CO., ATLANTIC CITY, WYO.

BY

CHARLES L. ROSS AND E. D. GARDNER

I. C. 6846,
June 1935.

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

PLACER-MINING METHODS OF E. T. FISHER CO.,
ATLANTIC CITY, WYO.[1]

By Charles L. Ross[2] and E. D. Gardner[3]

INTRODUCTION

A successful placer mine is being operated by the E. T. Fisher Co. on Rock Creek in the South Pass mining district at Atlantic City, Wyo. About 2,800 cubic yards of gravel is dug daily by a gasoline-driven dragline shovel with a 1 1/4-yard bucket and washed in a movable plant with a gold-dredge trommel and standard-dredge sluice boxes; the total cost is about 12 cents per cubic yard.

The gold-bearing gravel occupies a narrow valley between two low ranges of hills. The ground is covered by brush and willows, which are cleared off in the fall by burning after the leaves have dried. The elevation at the mine is 7,600 feet above sea level.

GEOLOGY

The channel ranges from 100 to 250 feet in width, the average being about 200 feet. The workable gold-bearing gravels extend along the creek for 14 miles. The proven depth of the gravel ranges from 9 to 12 feet; the average is 10 feet. The upper 3 feet of the deposit consists of barren loam, which is stripped and piled at the sides of the channel. The gravel is well-rounded and contains relatively few boulders. The screen oversize usually ranges up to the size of footballs. However, about a dozen boulders up to 18 inches in diameter are found each 8 hours of operation. Sixty-five percent of the material washed passes through the screen (minus 3/4 by 1-1/2 inches).

The gravel is easy-digging and free-washing. The bedrock, which has a slope of 2°, is diorite schist, of which the upper 2 to 5 feet has been decomposed into a tough, blue clay. Most of the gold occurs in the 6-inch stratum of gravel overlying the decomposed bedrock. The remaining gravel runs about 5 cents to the cubic yard. The gravel contains a relatively small amount of black sand - about a teaspoonful of sand to the pan of gravel.

1/ The Bureau of Mines will welcome the reprinting of this paper, provided the following footnote acknowledgment is used; "Reprinted from U. S. Bureau of Mines Information Circular 6846."

2/ Member of firm, E. T. Fisher Co., Atlantic City, Wyo.

3/ Supervising engineer, U. S. Bureau of Mines, Tucson, Ariz.

The gold is rounded and occurs in relatively small particles. Nuggets are rare. The largest found up to July 1934 was worth $105. This was caught in next to the last box under a section of the screen having 3/4- by 1-1/2 inch slots. A small part of the gold is rusty and does not readily amalgamate. The fineness of the gold ranges from 840 to 900; it contains 3 percent silver.

HISTORY

Gold was discovered in the district in the early days; a number of creeks were hydraulicked. Intermittent placer mining has been conducted in the district since then, mostly on a small scale until the present mine was begun. In June 1934 gold ore was being milled from one lode mine and development work was being conducted at three other underground properties in the district.

The grade of Rock Creek (2°) is insufficient to permit the gravel to be flumed; hence, the deposit had not been hydraulicked, although a company built a 20-mile ditch and prepared to do so at one time. The gravel was too shallow and too limited in extent to justify putting in a floating dredge at the old price of gold. A few spots of the creek had been mined by hand, but the quantity of gravel washed in this manner is insignificant.

The ground was sampled by the present operators in the summer of 1932. The washing plant was designed and fabricated at Seattle. Stripping of overburden and the construction of the washing plant were begun on May 20, 1933. Washing was begun on June 15. Operations ceased for the winter on October 25 after 320,000 cubic yards of material had been handled; this quantity included stripping, bedrock drains, waste ditches, and other dead work.

Stripping for the 1934 season began March 27 and washing May 15. A total of 420,000 cubic yards was washed in 1934. The season closed October 17. A distance of 4,700 feet along the creek was washed in 1933 and a total of 11,200 feet up to the end of 1934.

SAMPLING

The deposit was sampled by driving pipes through the gravel. A single row of holes 150 to 300 feet apart was put down first along the center line of the channel. Rows of holes 1/2 mile apart were then drilled across the deposit; holes in the rows were 20 to 60 feet apart. The spacing depended upon surface indications. The holes extended through the decomposed bedrock to solid rock and averaged 14 feet in depth.

The sampling device was a 4-inch casing with a Keystone cutting shoe. The diameter of the shoe was slightly less than that of the pipe; the samples were retained in the pipe when it was withdrawn. The casings were driven down to refusal with a locally made pile driver. This consisted of a 275-pound hammer, a 20-foot, 4-legged, pole derrick, and a Chevrolet automobile engine and transmission shaft. The cable for raising the hammer ran through a sheave at the top of the derrick to a drum on the transmission shaft. The

whole assembly was on a pair of skids and was moved forward by its own power; the end of the cable was attached to a deadman. The sampling outfit cost $300. to build.

The casings were pulled by means of a set of wire blocks having 4 and 5 sheaves. The cable from the blocks was wound on the drum by the engine. About half the time it was necessary to start the casing with jacks set against a clamp put around the top of the pipe. Three sets of casings were used. A pulled casing was laid on saw horses and the gravel removed in 6-inch sections by means of a special spoon; each section of gravel was panned.

The crew consisted of three men. The man in charge panned while the machine was being moved up and the next pipe driven. All three men pulled the casings. A total of 140 holes was put down in 2-1/2 months' time at a cost of $2,200, excluding traveling expenses. The cost per foot was $1.12. From 4 to 7 holes were driven daily when full time was spent in sampling. Four holes were lost because the pipe hit boulders. In these cases new holes were driven alongside.

After the sampling was completed the area was plotted, and the grade and amount of gravel were calculated. This was followed by sinking 46 shafts at average drillholes throughout the tract. These shafts were 4 by 6 feet and were sunk without timbering. The gravel from the shafts was washed in sluice boxes. Where the shafts were wet the water pumped from them while sinking was used in washing. Otherwise, sluicing was delayed until the shaft filled with water. A Larson, 2-inch high-speed, centrifugal pump, powered by a 1-1/2 hp. gasoline engine, was used to handle the water.

Two men sank a shaft each day while the third washed the gravel. The cost of sinking the shafts and washing the gravel was $1.50 to $4.00 per cubic yard of gravel.

The value of the gravel in the area tested, as calculated from the drill holes, averaged 19 cents per cubic yard (gold at $20.67 per ounce). The results of sluicing the gravel from the shafts indicated a value 15 percent higher (21.8 cents per yard). Actual recovery in washing has been very nearly 25 cents per cubic yard (42 cents at $35 per ounce). The discrepancy may be explained by the fact that in sampling all colors having a value of 1 cent or more were discarded.

WATER SUPPLY

The water supply is the natural flow of Rock Creek. About 50 miner's inches or 1-1/4 cubic feet per second is used in the plant. Up to July 1, 1934 no water was recirculated. However, due to the unusually dry season it was expected that part of the supply would have to be reused before fall.

The water is pumped through a line up to 1,200 feet in length of 12-inch, slip-joint, 14-gage pipe in 15-foot lengths at a pressure corresponding to a 50-foot head with a Byron Jackson centrifugal pump, direct-connected to a Climax 75 hp. gasoline engine. The engine required an average of 25 gallons of gasoline costing 20-1/2 cents per 8 hours.

The pump is picked up and moved by the dragline. Usually as the pump is reached it is moved upstream another 1,200 feet. Occasionally, however, it is picked up by the dragline and turned around on the same site and pipe added a length at a time until an advance of 1,200 feet is made. The dragline is then run down on top of the sand tailing to get the pump. A level place on which no overburden is deposited is left at each 1,200-foot interval. Less power is required when the pump is kept upstream from the plant.

A 48-foot length of pipe, held up by a truss guyed to the frame, extends at right angles from the washing plant. To this is attached 20 feet of hydraulic hose, which rests on a hinged apron from the end of the truss; one end of the apron rests on a berm at the original surface of the ground. A 90° elbow is attached permanently to the outer end of the hose. The elbow slips over the end of the pipe and is held in place by two chain tighteners permanently attached to the elbow. One end of the chain is placed around the pipe and the other end around the elbow and made fast.

DIGGING UNIT

The gravel is excavated with a power dragline with caterpillar traction, a 60-foot boom, and a 1 1/4-cubic yard bucket. A 1 3/4-cubic yard bucket came with the machine, but at the elevation of the mine the engine had insufficient power to handle the larger bucket. During the summer of 1934 a change was made from gasoline to 40-gravity fuel oil. More energy is generated with the new fuel, and future stripping will be done with the larger bucket. The gravel is dumped into the hopper of the washing plant 27 feet above level of the excavator. The shovel is oiled while the washing plant is being moved up.

The following tabulation gives the size and life of the cables on the dragline:

Cable	Diameter, inch	Length, feet	Life, days
Dragline	7/8	70	14 to 15
Hoisting line	7/8	134	25 to 35
Trip line	3/4	17	10 to 12

All cables are tru-lay. It takes an average of 5 minutes to replace a worn line. The 7/8-inch cable costs 35 cents per foot.

Bucket teeth last 2 to 4 days. After teeth are worn they are taken off and built up to size by welding on plow steel and a tip of stellite. Each tooth is treated twice in this manner before it is discarded. A new set of four teeth costs $20. Rebuilding costs $3 each, or $12 per set. A set of teeth can be replaced on the dipper in 10 minutes.

The shovel used about 25 gallons of gasoline, costing 20-1/2 cents per gallon per 24-hour shift. Forty-gravity fuel oil, which is to replace gasoline as a fuel for the shovel and the pump, costs 14-1/4 cents per gallon delivered. An average of 175 gallons of fuel oil and gasoline was used each 24 hours for all power purposes.

PLAN OF EXCAVATING

The creek was first diverted into a canal dug by the dragline at one side and 50 to 100 feet from the edge of the gravel channel. Stripping is done in two swaths. The shovel travels up one side and back the other. The machine can dig across a strip 180 feet wide without moving from side to side. As the gravel is stripped a drain ditch is dug 4 feet into the decomposed bedrock on either side of the tract to be worked. The overburden is piled in rows back of the drain ditches. The material dug from the ditches is piled on top of the gravel to be washed. On the creek side a berm is left next to the pit to hold the water pipe.

The stripping is kept a minimum of 50 feet ahead of the other work. Some stripping is done in the spring and fall when freezing weather prevents washing. During the spring of 1934 stripping was done 44 days before washing was begun. Until other operations catch up to the stripping (which will be about August 15), washing will be done on three shifts. Thereafter, stripping will be done on one shift (the midnight) and washing on the other two. Between 1,000 and 1,200 cubic yards of overburden (average, 1,150) is stripped per 8-hour shift.

The washing plant can handle the gravel as fast as the dragline can deliver it. The layout at Atlantic City is shown in figure 1. The washing plant is brought up near the center line of the pit. The distance to the creek side is kept constant on account of the water connections. Fifteen-foot cuts are taken across the channel. One cut is taken with the dragline set on one side of the line of the plant and the next with the excavator the same distance over on the other side. On the left side (looking downstream) a 40-foot jog is kept 15 feet ahead of the main face and on the right a 30-foot jog. This arrangement is a convenience in digging and saves moving the dragline twice for one cut. The washing machine is moved up 15 feet after each cut; this distance corresponds to the lengths in the water-supply pipelines. As the machine is moved up, one length of pipe is removed. Four moves are made each 24 hours. A move can be made in daylight in 35 minutes and after dark in 1 hour; the total time for 4 moves is 3 hours.

All digging is done dry. The bedrock is well-drained before it is taken up. When wet, it is sticky and hard to handle. From 18 inches to 2 feet of bedrock is washed. In digging, the bedrock material is mixed with the overlying gravel, which assist the washing. Large lumps of clay have a tendency to ball and pass through the trommel.

All work is done in an orderly and systematic manner. The overburden and screen oversize are piled in neat windrows. The sand tailings pile has the appearance of a wide highway.

During the 1934 season, up to July 1, 4 hours were lost while repairs were being made on the shovel and 3 days' time was lost pending delivery of parts for the water pump. The oil shaft on the pump broke on night shift, and the bearings burned out. No delays occurred on account of the washing plant.

WASHING PLANT

The washing plant consists essentially of a receiving pocket, a trommel, a gasoline engine, boxes with dredge riffles, a belt stacker for handling the oversize, and a tailings sluice. It runs on a 15-foot sectional track made of 90-pound rails laid on 4-by 10-inch by 3-foot ties laid on 18-inch centers. The rails are 15 feet 7 inches apart.

An embankment 4 feet high and 5 feet wide on top is built with the draglines for supporting each rail. At the start these embankments were only 18 inches high, but this height did not allow enough elevation for efficient disposal of the tailings. Furthermore, complete drainage was difficult. The track is laid level both ways. A 15-foot straightedge and a spirit level are used in leveling. The plant is moved forward by the dragline used as a tractor. The washer weighs 55 tons.

Each side of the machine is supported by seven cast-steel double-flanged wheels 16 inches in diameter. Four wheels are on the back end and three on the front, with a space of 12 feet between each set. The distance between the front and back wheels is 42 feet center to center. The end wheels have a 6-inch face, the next an 8-inch, and the other 3 on each side a 12-inch face The wider flanges of the center wheels permit turning the machine. Cast-iron wheels did not prove strong enough to support the load.

The hopper holds 3 bucketloads of gravel. Originally it was 6 by 7 by 11 feet, with a pyramid bottom; the size was cut to reduce the weight.

The trommel is 4 feet 6 inches in diameter; the screen surface is 12 feet long and the total length 22 feet. The rolls for turning the trommel run on the 5-foot blank space at either end. Beginning at the upper end there is 4 feet of 1/4-inch, then 4 feet of 1/2-inch holes. The lower 4 feet contains slots 3/4 by 1-1/2 inches long, which are made by drilling two 3/4 inch holes side by side. All holes are tapered to prevent blinding.

The trommel is turned at 14 r.p.m. The speed is adjustable, and when the feed has an unduly large proportion of clay the trommel is slowed. It is run by a 30-hp. Wisconsin engine that burns 10 gallons of gasoline per 8 hours. The trommel is built of manganese steel. No repairs had been necessary to July 1934.

The gold is saved in standard-dredge riffled sluices. Five 2-foot 4-inch boxes 12 feet long in parallel receive the screen undersize and discharge into a 72-foot tailings sluice 28 inches wide.

Riffles are 1-3/4 inches high, topped with 1/8-inch iron 1-3/8 inches wide and spaced 1-1/4 inches apart. They have a batter downstream, and the iron has an overhand of 1/8 inch. The same kind of riffles are used in the tailings sluice as in the inside boxes. The riffles are built in 1-foot sections. The boxes and tailings sluice are set on a grade of 19 inches to 12 feet (1-7/12 inches to the foot). No riffle repairs were necessary for the first season.

About 100 pounds of quicksilver is used in the riffles at a time. About 1/2 teacup is added to the boxes for each 400 cubic yards of gravel washed. The quicksilver loss for the 1933 season was about 30 pounds.

The stacker, consisting of a 26-inch rubber belt, is 40 feet long and set at right angles to the plant; the raise is 8 feet. It is run by the same engine that turns the trommel. It is considered that a stacker set at 45° with the line of advance and a correspondingly greater length would be an improvement, as it would permit better drainage back of the rock pile.

Whenever there is any delay in the feed to the washer the water is bypassed through a pipe on the stacker side of the machine.

TAILINGS DISPOSAL

As stated before, the oversize is piled by a belt stacker, and the sands are run out in a tailings sluice that discharges 8 feet above the bottom of the pit.

The sand tailings are directed by mud boards to the right (see fig. 1) in streams 7-1/2 feet wide at right angles to the line of advance. The boards are held by iron stakes driven into the tailings. As one course fills the boards are raised. Three sets of boards are used. The coarsest material settles near the point of discharge. The slime settles in a small basin at the right of the plant. A dike is made with the shovel after each cut from the track embankment to the side of the pit to keep the drainage water back. The fines spread out to the left until stopped by the rock pile. The water reaches the drainage ditch on the left by passing back of the washing plant. The ditch on the right is allowed to fill. The top of the tailings presents a smooth surface. One man works on the tailings dump continuously when the plant is running.

CLEANING UP

The inside boxes and the upper end of the tailings sluice are cleaned up every 10 days. Eighty percent of the hard amalgam is obtained in the upper 3 feet of the boxes. The lower end of the sluice is cleaned up every 20 days, mainly to open the riffles. During this period packed black sand about fills the space between the riffles.

In cleaning up, clear water is run through the boxes to wash off all light material. Beginning at the head of each box, each 1-foot section of riffles is taken up in turn. The hard amalgam, which is left behind as the other material is moved downward by the clear water, is scooped up. The live quicksilver, together with about 3 gallons of concentrate, is removed from each 12-foot box for further treatment. About eight 3-gallon buckets of material, including 3 from the tail sluice, are handled from each clean-up. Considerable black sand is washed over during the clean-up.

After cleaning up the riffles are replaced, new quicksilver is added, and the plant is started. About 2 1/2 hours is required for cleaning the boxes.

The concentrate is treated first in a steel sluice with a puddling box at the head to separate out the live quicksilver. The material is stirred with whisk brooms to cause droplets of quicksilver to coalesce. Most of the black sand is run to waste. The riffle product from the steel box is treated in two batches in a 2- by 4-foot cylindrical amalgamation barrel that is turned 40 r.p.m. by a 1-1/2 hp. gasoline engine. Enough water to make a thick pulp and about 5 pounds of quicksilver are added to each batch, which is ground 35 minutes. Old cast-iron bucket teeth are used as grinding media. When there is any indication of grease in the concentrate a can of lye or a tablespoon of cyanide is placed in the barrel. The material from the clean-up barrel is run through the steel clean-up box again, and the amalgam and live quicksilver are recovered. The remaining black sands are run to waste. One man requires about 6 hours to treat the concentrate from one clean-up. The live quicksilver from both clean-up operations is strained through bags of 8-ounce canvas; it is then ready to reuse. The amalgam is squeezed by hand and retorted in a gold room at the office; the sponge gold is shipped to the mint. About 650 wet ounces of amalgam produces a brick worth $10,000.

CONSTRUCTION AND COST OF PLANT

As stated before, plans were drawn and the machinery for the washing plant fabricated at Seattle. The total equipment and supplies were shipped in three cars, the dragline in one, lumber in the second, and machinery and miscellaneous equipment in the third.

The screen posts of the plant are of 12- by 12-inch timber. Ten- by ten-, eight- by ten-, and four- by six-inch timber was used elsewhere. In all a total of 30,000 board feet was required, including buildings.

The cost of the plant and equipment was as follows:

Dragling shovel, (used)	$14,000
Pumps	250
Engine for driving pump (secondhand)	750
Trommel	
Other equipment for washing plant	9,150
Timber	
Construction of plant, labor, and supplies	
Freight, Seattle to Rock Springs, Wyo.	2,300
Trucking, Rock Springs to Atlantic City, Wyo., 105 miles	750
	$27,200

The shovel was "walked in" from Rock Springs to Atlantic City on its own power in 12 days. The timber for the plant was framed on the ground. The plant was constructed in 13 days. Thirty days after the work was begun the first clean-up from 16,000 yards of gravel was made.

LABOR

Six men work on both day and afternoon shifts and five on night shift. The labor force for operating the plant on the three-shift basis is as follows:

Number	Classification	Rate	Totals
3	Shovel runners	$10.00	$30.00
3	Oiler (shovel) and general utility	4.00	12.00
3	Screen attendants	4.00	12.00
3	Tailings attendants	4.00	12.00
2	Trackmen [1/]	4.00	8.00
3	Bosses (members of firm)		
17			$74.00

1/ The trackmen work on day and afternoon shifts only.

MINING COSTS

The daily cost at the plant is about $150, divided about equally between labor and supplies. Mining costs for 1934 are shown in tables 1 and 2. The cost of removing the overburden, including digging the ditches, was $0.05 per cubic yard. This expense is included in tables 1 and 2.

TABLE 1. - Operating costs, E. T. Fisher Co., 1934
(240 days worked; 420,000 cubic yards handled;
average value recovered, $0.2375)

Item	Amounts		Per cubic yard
Labor	$ 14,742.00		
Workmen's accident compensation	247.94		
Salaries (supervision)	3,725.00		
Oil and gasoline	7,805.13		
Other operating supplies	3,119.04		
Repair supplies [1/]	6,666.85		
Freight and express	1,022.89		
General costs	410.00		
Telephone and telegrams	95.79		
Total direct		$ 37,834.64	$0.090
Taxes	874.34		
Rent	260.00		
Royalty	6,968.00		
Insurance	59.44		
Depreciation	3,097.70		
Total indirect		11,259.48	.029
Grand total		$ 49,094.12	.119

1/ Includes new bucket, stacker belt, and changing engine over from gasoline to oil-burning.

TABLE 2. - Summarized operating costs, E. T. Fisher Co., 1934

Item	Per cubic yard	
Labor	$ 0.036	
Fuel for power	.018	
Other operating supplies	.007	
Repair supplies	.016	
Supervision	.009	
Miscellaneous	.004	
Total direct		$ 0.090
Royalty	.017	
Depreciation	.008	
Others indirect	.003	
Total indirect		.029
Grand total		.119

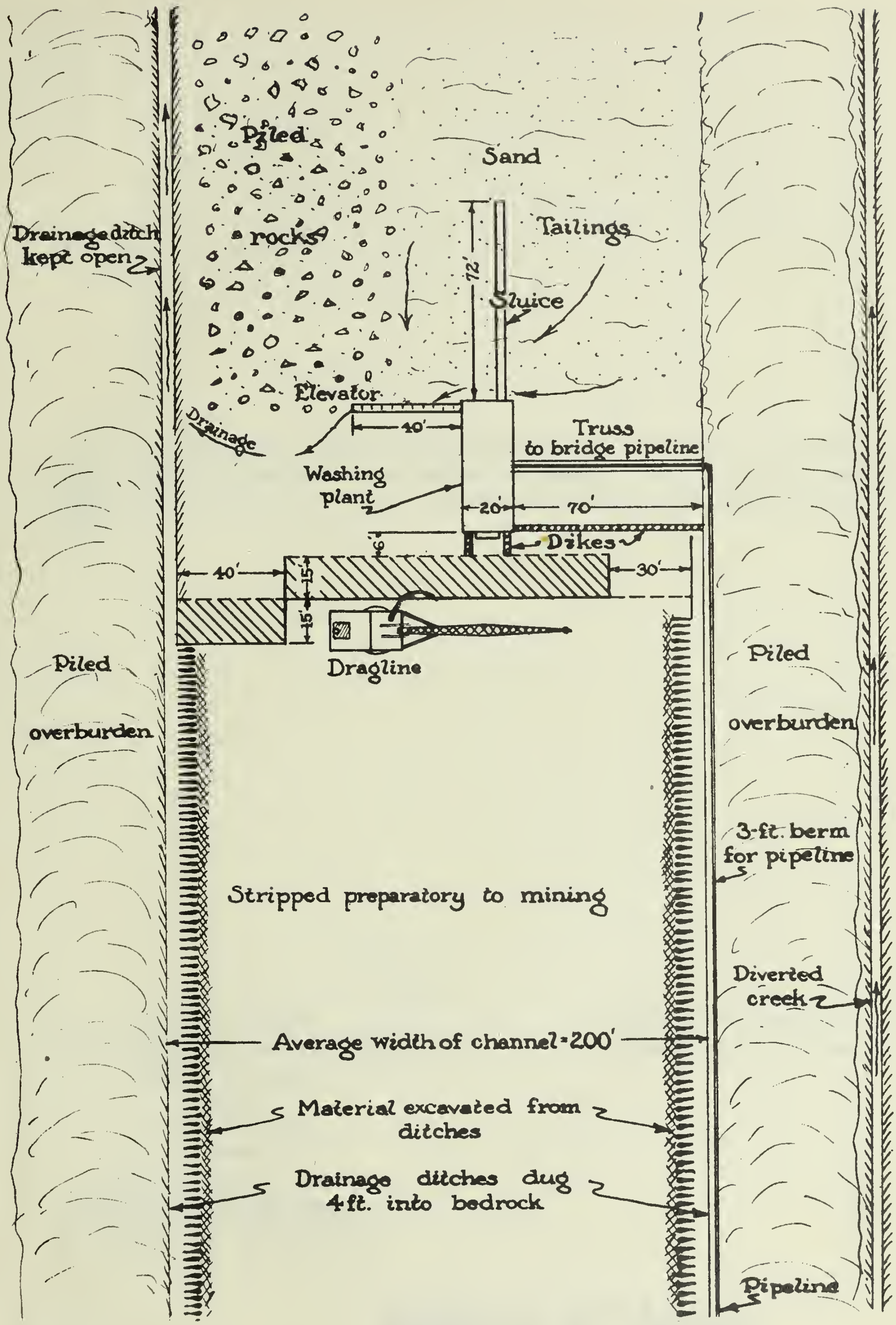

Figure 1.– Layout of E. T. Fisher Co. placer, Atlantic City, Wyo.

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July 1935

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UNITED STATES BUREAU OF MINES
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INFORMATION CIRCULAR

THE RARE EARTHS

BY

Alice V. Petar

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July 1935

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

THE RARE EARTHS[1]

By Alice V. Petar[2]

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2/ Rare Metals and Nonmetals Division, U.S. Bureau of Mines.

INTRODUCTION

The rare-earth group are among the least familiar of the 92 known elements. Moreover, the relatively few people who have even heard of the rare earths ordinarily regard them merely as very rare elements having unusual names but doubtful commercial application. This typical attitude can be attributed partly to the fact that no commercial uses have been developed for most of the members of the group and partly to the fact that those which do enter into useful articles do so anonymously. Most people speak with a degree of familiarity of the "chromium" plating on their automobiles or household appliances; "antimony" ash trays and cigarette boxes are on sale in many department stores; and "tungsten" lamps and even "molybdenum" steels are advertised in popular magazines. However, the average user of a pocket cigarette lighter is not conscious that the important sparking element is a "flint" made from ferrocerium, and if he does chance to inquire about the composition he is likely to be told that it is "sparking alloy", "misch metal", or "pyrophoric alloy." Similarly, the wearer of spectacles made of "Crookes" or other tinted glass probably is not aware that the light softening effects are due to the presence of rare-earth oxides, or that the arc light on his street may owe its brilliance to cerium fluoride in the carbon electrode. Despite a variety of practical applications, however, most of the rare-earth metals still must be listed as scientific curiosities. In fact, little is known as to the properties which may make them useful products at some future date. Meanwhile it is important to note that Nature has been relatively generous in her distribution of the rare earths and that adequate supplies of most of them will be forthcoming when these elements have proved their worth as commercial products.

ACKNOWLEDGMENTS

In preparing the present paper abundant use has been made of information contained in an earlier circular, which is now out of print--Bureau of Mines Information Circular 6321, Monazite, Thorium, and Cerium, by R. M. Santmyers. The author has also used extensively J. F. Spencer's The Metals of the Rare Earths, J. W. Mellor's Comprehensive Treatise on Inorganic and Theoretical Chemistry (vol. 5), and other works which are acknowledged in footnotes or referred to in the bibliography. Grateful acknowledgment is made of helpful criticism of the manuscript, prior to publication, by Dr. Harlan S. Miner, of the Welsbach Co., Gloucester City, N. J.

DESCRIPTION AND PROPERTIES

In group III of the Periodic Table of the Atoms there appears a single item entitled "Rare Earths" which includes the elements having atomic nos. 57 to 71. The individual elements of this group, in order of increasing atomic weight, are as follows:

Rare-earth elements

Element	Symbol	Atomic No.	Atomic Weight
Lanthanum	La	57	138.92
Cerium	Ce	58	140.13
Praseodymium ..	Pr	59	140.92
Neodymium	Nd	60	144.27
Illinium	Il	61	?
Samarium	Sm	62	150.43
Europium	Eu	63	152.0
Gadolinium	Gd	64	157.3
Terbium	Tb	65	159.2
Dysprosium	Dy	66	162.46
Holmium	Ho	67	163.5
Erbium	Er	68	167.64
Thulium	Tm	69	169.4
Ytterbium	Yb	70	173.04
Lutecium	Lu	71	175.0

Higher up in the same vertical column of the chart but closely related to this group are two other elements, scandium (atomic no. 21) and yttrium (atomic no. 39).

Strictly speaking, the term "rare earths" denotes the oxides, but it is employed conveniently in referring to the elements themselves. The known properties of the individual members of the group are characteristically similar, and ordinarily the elements occur together in the same minerals and are difficult to separate. There are also subgroups or "families"; one arrangement, based on the solubility of the rare-earth oxalates in a saturated solution of potassium sulphate, is as follows:3/

Subgroups of the rare earths4/

- Insoluble oxalate (Rare earth)
  - Insoluble potassium sulphates (cerium family)
    - Lanthanum
    - Cerium
    - Praseodymium
    - Neodymium
    - (Illinium)
    - Samarium
  - Moderately soluble K sulphates (terbium family)
    - Europium
    - Gadolinium
    - Terbium
  - Readily soluble K sulphates (yttrium family)
    - (erbium family)
      - Dysprosium
      - Holmium
      - Erbium
      - Thulium
    - (ytterbium family)
      - Yttrium
      - Ytterbium
      - Lutecium

3/ For a simpler arrangement see section on History, p. 8.
4/ Mellor, J. W., A Comprehensive Treatise on Inorganic and Theoretical Chemistry: vol. 5, Longmans & Co., London, 1924, p. 495. (Illinium has been arbitrarily inserted in the "cerium family" because of its position, between neodymium and samarium, in the periodic table.

Considerable literature covers the circumstances of the discovery and gradual refinement of laboratory procedure of these elements, but the details are too technical for inclusion in a general report. The Bureau of Mines has made no special study of the properties of the rare earths; in fact, a large part of the research has been done by European investigators. However, a member of the group, illinium, is one of the few elements discovered in the United States. The following descriptions of the individual rare earths have been abstracted from available literature.

Cerium Family

Members of the cerium family are the only ones of the rare-earth group about which much is known. Except for the recently discovered element 61, illinium, these "earths" have all been employed commercially, either individually or collectively, as "misch metal." The elements in the cerium group are strongly electropositive and are among the most basic of all elements. They are also distinguished from the other rare earths by the fact that they form sparingly soluble double sulphates with sodium and potassium sulphates. The following table summarizes available information with respect to the properties of lanthanum, cerium, praseodymium, neodymium, and samarium.

Properties of elements of cerium family

Element	Atomic Weight	Color	Hardness	Specific	Melting Point, °C.
Lanthanum	138.92	Tin-white	Harder than Ce	6.15	810
Cerium	140.13	Steel-gray	Nearly as soft as lead.	6.9	623
Praseodymium ...	140.92	Yellow	Harder than Nd	6.47	940
Neodymium	144.27	Yellow tinge	Harder than Zn	6.95	840
Samarium	150.43	Pale gray	Hard as steel	7.7-7.8	1,300-1,400

Cerium. - The term "cerium" frequently is used to describe a mixture of the metals of the cerium group having approximately the following composition: Cerium 45 percent, lanthanum 25 percent, neodymium and praseodymium 15 percent, and samarium 10 percent.[5/] This mixture is employed for a number of purposes where there is no special advantage in separating the individual elements. The following description applies to the element cerium.

Cerium metal resembles steel in appearance; it is lustrous, malleable, very ductile, and soft enough to cut with a knife. It conducts electricity poorly and heat fairly well, and emits sparks when scraped with a file. Cerium is stable in dry air but is oxidized superficially in moist air. It burns more easily than magnesium when heated in air, forming oxide and producing heat and much light. It ignites spontaneously when finely divided and burns in vapors of nitrogen, hydrogen, bromine, iodine, sulphur, and phosphorus,

5/ Gillett, H. W., and Mack, E. L., Molybdenum, Cerium, and Related Alloy Steels: Chem. Catalog Co., New York, 1925, p. 89.

forming compounds with these elements. Cold water attacks it slowly and hot water quickly. It is not attacked by cold, concentrated sulphuric acid, or red, fuming nitric acid, and is soluble in dilute sulphuric acid, nitric acid, and dilute or concentrated hydrochloric acid, but insoluble in sodium hydroxide. Cerium forms alloys with many metals and forms both cerous and ceric compounds.[6]

Lanthanum. - Lanthanum is a white, malleable, ductile metal, harder than cerium but softer than zinc. The metal takes a high polish, which tarnishes immediately in dry air as it becomes coated with a steel-blue film. Lanthanum burns in chlorine and bromine but less brightly in the latter, and it unites with iodine without producing light. It decomposes slowly in cold water and rapidly in hot water, is soluble in dilute acids, and is attacked easily by cold, concentrated nitric acid but not by cold, concentrated sulphuric acid.[7] Owing to the solubility of its salts, lanthanum is the easiest of the rare-earth metals to separate by fractional crystallization. It is the most strongly electropositive rare-earth metal and in its properties is closely related to calcium and magnesium. Lanthanum may be alloyed[8] with lead, tin, thallium, magnesium, silver, copper, and gold; most of the alloys are pyrophoric. Investigations at the University of California indicate that lanthanum is slightly radioactive.[9]

Praseodymium. - Metallic praseodymium has a faint yellow color and is acted on very slowly by air. It is harder than neodymium but not as hard as samarium. Praseodymium forms two well-defined oxides (Pr_2O_3 and PrO_2), a hydrated peroxide of the formula Pr_2O_5, and possibly other oxides intermediate between Pr_2O_3 and PrO_2. Praseodymium salts are greenish and analogous to the cerous and lanthanum salts. Alloys of praseodymium with aluminum and magnesium have been studied by Canneri,[10] who found that in properties, including the pyrophoric characteristics, they are similar to the corresponding lanthanum alloys. Praseodymium is closely related to neodymium, and the two elements have many common properties. For some industrial purposes the mixture of the two, didymium, is employed.

Neodymium. - Neodymium is a faintly yellow metal, it is moderately stable in air, although after some hours it becomes covered with a grayish coating of oxide. It is attacked slowly by cold water but rapidly by hot water. Acids dissolve it rapidly, but solutions of alkalis act on it in the same way as pure water.

6/ Segerblom, Wilhelm, Properties of Inorganic Substances: Chem. Catalog Co., New York, 1927, p. 165.

7/ Segerblom, Wilhelm, work cited, p. 173.

8/ Canneri, G., (The Alloys of Lanthanum): Metal. ital., vol. 23, 1931, pp. 802-823. Chem. Abs., vol. 26, no. 4, Feb. 20, 1932, pp. 949-50.

9/ Science News Letter, Three Rare-Earth Elements Proved to be Radioactive: Vol. 23, no. 619, Feb. 18, 1933, p. 99.

10/ Canneri, G., (Alloys of Praseodymium and Aluminum): Alluminio, vol. 2, March-April 1933, pp. 87-89; Metals and Alloys, vol. 5, no. 4, April 1934, p. MA157. (Alloys of Praseodymium and Magnesium): Metal ital., vol. 25, 1933, pp. 250-252; Chem. Abs., vol. 27, no. 21, Nov. 10, 1933, p. 5293.

Neodymium is said to be an almost ideal decolorizing agent in glass, as it produces remarkably little loss of transparency in ultraclear glass. Usual decolorizers absorb much of the light necessary for physiological colorlessness, causing the glasses to appear dark.[11] According to Prof. R. W. Wood, of Johns Hopkins University,[12] rods of quartz, in which a compound of neodymium has been dissolved, when heated give a light from which certain colors are missing; the spectrum is crossed by dark bands. Unlike white-hot incandescent wires such as tungsten filaments, which give a white light that includes all the possible colors, neodymium sends out only special vibrations of its own. Ne dymium is said to be radioactive.

Samarium. - Metallic samarium is grayish white and tarnishes in air. It is the hardest of the cerium metals and very brittle. The salts are topaz-yellow. Like lanthanum and neodymium samarium has been found to be radio-active.[13]

Illinium. - In 1926 Prof. B. S. Hopkins, of the University of Illinois[14] announced the discovery of element 61, to which he gave the name illinium. Little information is available as to the properties of the element. Professor Hopkins identified it by X-ray spectroscopic means while mapping the arc spectrum line of elements 60 (neodymium) and 62 (samarium). The element was isolat in 1933 by Maurice Curie and M. Takvorian, of the Radium Institute of Paris.[15] No illinium compounds have been reported.

Terbium Family

Published information relative to members of the terbium family is largely historical and is summarized briefly in this report under "History." A recent paper by Hopkins[16] on europium states that it is one of the rarest chemical elements. The best estimates now available indicate that it comprises about two millionths of 1 percent of the earth's crust. It has a remarkably persiste spectrum which is easily identified. In consequence, the presence of europium in the sun and some of the fixed stars has been demonstrated. Europium salts form pink solutions. No commercial uses have been suggested for europium or its compounds.

11/ Loeffler, Johannes, (Why Neodymium is a Better Physical Decolorizer Than Nickel, Cobalt, Manganese, or Selenium): Sprechsaal, vol. 66, 1933, pp. 629-630.

12/ Science News Letter, Rare Element Gives New Kind of Light: Vol. 19, May 2, 1931, p. 276.

13/ Science News Letter, Three Rare-Earth Elements Proved to be Radioactive: Vol. 23, no. 619, Feb. 18, 1933, p. 99.

14/ For a detailed account of investigations leading to discovery of the element see Hopkins, B. S., Illinium - The New Rare Earth: Jour. Franklin Inst., vol. 204, July 1927, pp. 1-11.

15/ Metal Industry (London), Illinium: Vol. 42, no. 16, Apr. 21, 1933, p. 432.

16/ Hopkins, B. S., Europium, a Rare Member of the Rare Earth Group: Paper presented at 66th Gen. Meeting of the Electrochem. Soc., Sept. 27 to 29, 1934, Preprint 66-16, pp. 167-174.

Gadolinium and terbium salts form colorless solutions. Known compounds include the bromides, carbonates, chlorides, hydroxides, nitrates, oxides, sulphates, and sulphides. Terbium metal has not been isolated.

Yttrium Family

The yttrium family of the rare earths is made up of two branches - an erbium subgroup and an ytterbium subgroup. All the elements of the erbium subgroup - dysprosium, holmium, erbium, and thulium - were separated from the original erbium (the "terbium" discovered by Mosander in 1843). The metal erbium is described as a dark-gray, metallic powder of specific gravity 4.77 at 15°. It decomposes in water and its salts give rose solutions. Erbium oxide (erbia) is a rose tinted powder, which is infusible and difficultly soluble in warm nitric acid, sulphuric acid, or hydrochloric acid. Its specific gravity is 8.6. The sulphate is soluble in water and has a specific gravity of 3.7. Dysprosium chloride, nitrate, and sulphate are yellow crystalline salts. The oxide is a white powder, soluble in acids, having a specific gravity of 7.8. Holmium oxide (holmia) is a pale-yellow powder, which is insoluble in water but soluble in acids to solutions which produce yellow or orange salts. Thulium oxide (thulia) is a dense white powder with a greenish tinge which when heated glows, first red, then yellow, and finally white. It is slowly soluble in hot, concentrated acids.

The ytterbium subgroup is composed of the elements yttrium, ytterbium, and lutecium. At one time it was believed that an additional element (celtium) belonged to this subgroup. Urbain claimed the discovery of celtium as the result of the fractionation of ytterbium from gadolinite; he also considered that the lines of the spectrum of celtium were in agreement with an element in the periodic table having the atomic number 72. However, the existence of "celtium" as a new element was disproved later, and the credit for the discovery of element 72 (hafnium) went to D. Coster and G. von Hevesy. The atomic number of yttrium (39) is outside the range of numbers of the rare-earth group, but the element is associated intimately with the rare earths in nature and was one of the two original sources from which the rare-earth elements were gradually separated. (This relationship is discussed more fully under "History.") Somewhat impure metallic yttrium has been prepared as an iron-gray powder which is oxidized readily in air and converted into the hydroxide by boiling water. Yttrium is easily soluble in dilute acids; its melting point is 1,490° C. and its boiling point 2,500° C. Its specific gravity is 5.51.

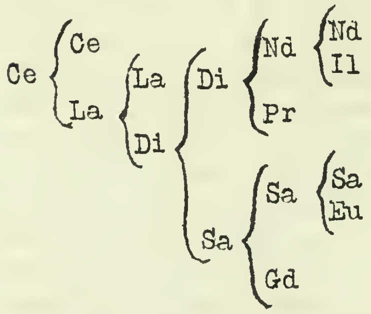
Available information on the properties of ytterbium and lutecium is meager. Solutions of their salts are colorless. Ytterbium oxide (ytterbia) is a heavy, white, infusible powder, slowly soluble in cold acids and easily and rapidly soluble at 100° to colorless solutions. Its specific gravity is 9.2. The sulphate is a white, opaque solid having a specific gravity of 3.8. It is soluble in water and decomposed by heat. The chloride is easily soluble in water, is decomposed to oxychloride by heat, and is soluble in alcohol. The melting point is 150° and the specific gravity 2.6. Lutecium chloride is probably more volatile and more soluble than the ytterbium salt. Its melting point is 916° and its specific gravity 3.9.

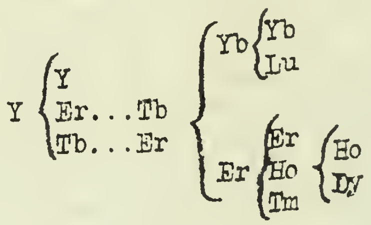
Scandium

Scandium, like yttrium, does not belong to the rare-earth group but is linked almost inseparably with elements in the group by association in nature, history, and properties. Scandium is present in many, but not all, rare-earth minerals. According to Urbain and Sarker,[17] scandium resembles the rare earths in analytical characteristics, insolubility of fluorides, and slight solubility of oxalates. Other salts of scandium differ widely. Metallic scandium has not been isolated. Additional information will be found in Bureau of Mines Information Circular 6401.[18]

HISTORY

The genealogy of the rare-earth family has been traced back to two oxides - yttria, which became known in 1794, and ceria, identified in 1803. The "descendants" of the yttria branch of the family are yttria, terbia, erbia, ytterbia, lutecia, holmia, thulia, and dysprosia, and the ceria group includes ceria, lanthana, neodymia, praseodymia, samaria, gadolinia, europia, and illinia. Diagrams of the rare-earth "family tree" were prepared by the late Prof. Charles James of the University of New Hampshire for the fourteenth edition of the Encyclopedia Britannica, and as they afford a condensed history of the progressive unfolding of our knowledge of the group they are reproduced here:





The following historical summary of the discovery of the rare earths has been abstracted from a paper by Weeks.[19]

The Scandinavian Peninsula may well be described as the ancestral home of the rare earths as the first rare-earth mineral was found at Ytterby, a little town near Stockholm, in 1788. In 1794 Jacob Gadolin, a Finnish scientist, discovered in this mineral a new earth, which subsequently was named "yttria."

17/ Urbain, G., and Sarkar, P. B., The Analogies of Scandium With the Rare Earth Elements and with the Tervalent Elements of the Iron Family: Compt. rend., t. 185, 1927, pp. 593-596; Chem. Abs., vol. 22, 1928, p. 200.

18/ Petar, Alice V., Gallium, Germanium, Indium, and Scandium: Inf. Circ. 6401, Bureau of Mines, 1930, 17 pp.

19/ Weeks, Mary Elvira, The Discovery of the Elements. XVI. The Rare-Earth Elements: Jour. Chem. Education, vol. 9, 1932, pp. 1751-1773.

The parent mineral was called "gadolinite." In 1803 Klaproth discovered in the mineral cerite another earth, which is now known as "ceria." Two other investigators, Berzelius and Hisinger, who were searching for yttria, also discovered ceria. In 1839 Carl Gustav Mosander found a new earth in ceria which he named "lanthana." In the same year Erdmann discovered lanthana in a new Norwegian mineral, which he named "mosandrite", in honor of Mosander. During the next few years Mosander continued his studies of lanthana and in 1841, after treating it with dilute nitric acid, extracted a new rose oxide which he named "didymium" because it seemed to be "an inseparable twin brother of lanthanum." Didymia was regarded as a pure earth until 1885 when Auer von Welsbach decomposed it. Mosander then turned his attention to yttria in an effort to determine whether it, like ceria, was composed of more than one element. In 1843 he showed that yttria from which all the ceria, lanthana, and didymia have been removed contains at least three other earths. These are a colorless oxide, for which he kept the name "yttria", a yellow earth, erbia, and a rose one, terbia. Other investigators confirmed Mosander's work, but in some way the names "erbia" and "terbia" were interchanged. In 1878 the Swiss chemist Marignac extracted from erbium nitrate two oxides - a red one for which he retained the name "erbia" and a colorless one which he named "ytterbia." The following year Nilson isolated the earth "scandia" from ytterbia.

The erbia left after the removal of ytterbia and scandia was resolved still further by Per Theodor Cleve into three constituents: Erbia, holmia, and thulia. In 1879 Boisbaudran detected the presence of a new oxide in didymia, which he named "samaria." In 1886 he obtained from it still another earth, which proved to be identical with a substance that Marignac had separated from samarskite in 1880. With the consent of the earlier investigator Boisbaudran named this oxide "gadolinia." As previously mentioned Carl Auer von Welsbach in 1885 succeeded in splitting didymia into two earths, for which he proposed the names "praseodymia" and "neodymia." To Baron von Welsbach goes the credit for putting the rare earths to work with his invention of the incandescent gas mantle; as first developed, the mantle fabric was impregnated with a mixture of lanthana and zirconia. His first patent for the Welsbach mantle was dated September 23, 1885. Baron von Welsbach also invented the automatic gas lighter based on a pyrophoric alloy of iron and cerium.

In 1886 Lecoq de Boisbaudran separated pure holmia into two earths, which he called "holmia" and "dysprosia." Europium was discovered in 1901 by Demarçay as a result of an elaborate series of fractionations of samarium magnesium nitrate. In 1907 Georges Urbain separated ytterbia into two constituents, which are now known as "ytterbia" and "lutecia." Before the news of Urbain's discovery reached America the late Prof. Charles James of the University of New Hampshire had prepared a large amount of very pure lutecia but refrained from pushing his claim for priority of discovery.

The most recent rare-earth element to be discovered is illinium, which was reported by Prof. B. S. Hopkins, of the University of Illinois, in 1926. Shortly after Professor Hopkins' announcement prior claim for the discovery of element 61 was made by Prof. L. Rolla, of the University of Florence. The

latter investigator based his claim on research done a few years previously which he believed indicated the existence of a new element. A description of his work was deposited with the Italian Academy in 1924 in a sealed package, which was brought to light and published after Professor Hopkins' announcement. Professor Rolla proposed the name "florentium" for his discovery. Such controversies have accompanied the discovery of many of the elements, and in this instance writers on both sides of the Atlantic soon expressed their opinions as to the relative merits of illinium and florentium as "contenders" for the position of element 61 in the periodic table. The work of Professor Hopkins and the name "illinium" apparently have been accepted.

OCCURRENCE

That the rare earths are not so scarce as their name implies is stated authoritatively by B. S. Hopkins, discoverer of illinium and recognized authority on the rare earths. He says [20] in part:

> The [rare-earth] group as a whole is as abundant in the earth's crust as such useful elements as cobalt, boron, zinc, lead, or arsenic. Indeed, the supply of the single element cerium, the most abundant member of the rare-earth group is probably larger than that of cadmium, tin, mercury, antimony, molybdenum, silver, tungsten, bismuth, gold, or platinum. Indeed, the rarest member of the rare-earth group, the recently discovered element illinium, is probably more than a thousand times as abundant as radium whose commercial importance cannot be denied. As a consequence it may be fairly safe to state that the present limited use of the members of the rare-earth group is due to our lack of information and not to a scarcity of material.

20/ Hopkins, B. S., Europium, a Rare Member of the Rare-Earth Group: Paper presented at 66th Gen. Meeting of the Electrochem. Soc., Sept. 27 to 29, 1934. Preprint 66-16, pp. 167-168.

Abundance of rare earths

Atomic no.	Symbol	Percent of rare-earth group1/	Percent in earth's crust2/
57	La	7	0.00007
58	Ce	31	.00031
59	Pr	5	.00005
60	Nd	18	.00018
61	Il	3/.02	.0000002
62	Sm	7	.00007
63	Eu	.2	.000002
64	Gd	7	.00007
65	Tb	1	.00001
66	Dy	7	.00007
67	Ho	1.2	.000012
68	Er	6	.00006
69	Tm	1	.00001
70	Yb	7	.00007
71	Lu	1.5	.000015
		99.92	

1/ Estimates of Goldschmidt and Thomassen, Geochemical Law of Distribution of the Elements III; Videnskapsselskapets Skrifter I Matemat-Naturv Klasse, no. 5, 1924, p. 49.

2/ These estimates are calculated from Dr. H. S. Washington's statement that the entire rare-earth group comprises about 0.001 percent of the earth's crust.

3/ This estimate is based on the statement by Dr. G. R. Sherwood that the illinium content of monazite is approximately one tenth that of europium. This ratio undoubtedly does not apply to other rare-earth ores.

RARE-EARTH MINERALS

Dozens of rare-earth minerals are known, but none provides so abundant or economical a source of raw material as monazite. An incomplete list of minerals containing the rare earths follows:

Minerals containing rare earths

Mineral	Composition	Rare-earth content	Occurrence
Aeschynite .	Niobate and titanate of the cerium metals	18% ceria; 6% mixed rare earths.	Southern Urals, Norway, and Silesia.
Allanite ...	Silicate of Ca, Al, and Fe with rare-earth oxides Ce, La, Di and Yt.	Ce oxides up to 27%; Yt oxides less than 3%	Colorado, New Jersey., New York, North Carolina, Pennsylvania, Texas, Virginia, and Wyoming, Massachusetts, Connecticut; Canada, Greenland, Scotland, Norway, Silesia.

Minerals containing rare earths-Cont'd

Mineral	Composition	Rare-earth content	Occurrence
Cappclenite	Borosilicate of yttrium and barium, with small quantities of Ce, La, and Th oxides.	57% mixed rare earths.	Found sparingly on Lille Arö, southern Norway
Cenosite ...	Hydrous calcium-yttrium silicate and carbonate.	37% yttrium oxides	Island of Hitterö, Norway.
Cerite	Silicate of cerium-group metals with Fe and Ca.	50-70% ceria	Colorado and Bastnäs, Sweden.
Delorenzite	Complex titanate of rare earths.	14% yttria	Craveggia, Italy.
Eucolite Eudialyte	Complex silicate of rare-earth metals with Ca, Fe, and high percentage of ZrO_2.	5% mixed rare-earth oxides.	Arkansas; Greenland, Norway.
Euxenite ...	Niobate and titanate of Yt, Er, Ce, and U.	13-27% yttria; 3-9% erbia; 2-8% ceria	Jölster, Norway.
Fergusonite	Metaniobate and tantalate of Yt with Ce, U, etc.	18-26% yttria; 8-13% erbia; 1-9% ceria.	Massachusetts, North Carolina, Texas, Virginia; Australia.
Gadolinite .	Baxic orthosilicate, chiefly BeO, iron protoxide, and yttrium oxides.	51% rare-earth oxides.	Arizona, Colorado, Texas; Norway and Sweden.
Lanthanite .	Hydrous lanthanum carbonate.	52.4% lanthanum trioxide.	New York, Pennsylvania; Sweden.
Monazite ...	Phosphate of the cerium metals.	See analyses, pp. 14,15 and 17.	Arizona, California, Colorado, Connecticut, Florida, Indiana, Montana, Nevada, New Mexico, Oregon, South Dakota, Texas, Utah, Virginia, Washington, Wyoming; Australia, Brazil, Ceylon, China, India, Japan, Madagascar, Norway.
Parisite ...	Fluocarbonate of the cerium metals.	37% Ce, 6% La, 8% Di	Colombia, Norway.
Polycrase ..	Niobate and titanate of Yt, Er, Ce, and U.	13-27% yttria; 6-8% erbia; 2-3% ceria.	North and South Carolina, Texas; Norway, Sweden.
Samarskite .	Niobate and tantalate of Fe and Ca with Ce and Yt metals and uranium oxide.	6-15% yttria; 2-6% ceria,	North Carolina, New Mexico; Canada, India, U.S.S.R., Brazil.

Minerals containing rare earths-Cont'd

Mineral	Composition	Rare-earth content	Occurrence
Rowlandite .	Yttrium silicate	61% yttria	Llano County, Texas.
Xenotime ...	Yttrium phosphate	do	Georgia, North Carolina, Colorado; Norway, Sweden, Switzerland, Brazil.
Yttrialite .	Silicate of thorium and yttrium oxides.	46% yttria	Llano County, Tex.
Yttrocerite	Fluoride of Ca with metals of Ce and Yt groups.	14% yttria and 9% ceria.	New York, Maine.
Yttro-tantalite	Tantalate and niobate of Fe, Ca, and oxides of Yt, Er, Ce, and U.	10-19% yttria; 6% erbia; and 2% ceria.	Ytterby, Sweden.

Monazite

Monazite is virtually the only commercial "ore" of the rare earths. It has been valued chiefly for its thoria content, which in high-grade commercial material may range from 6 to 9 percent, but ceria, lanthana, neodymia, praseodymia, and other rare earths are present in substantial percentages.

In minor quantities monazite is distributed widely in igneous rocks throughout the world, especially in gneisses that have been intruded by pegmatites, but usually it forms only a very small fraction of 1 percent of the containing rock, and only the natural concentrations in stream gravels and beach sands have paid for exploitation. The commercial deposits of monazite, like placer-gold deposits, are the result of decomposition of the rocks containing the mineral. Monazite, like gold, is not readily attacked chemically by the agencies of erosion, and as it is much heavier than most of the other products of rock degeneration it is concentrated gradually by stream and wave action. River waters will effect a concentration of the heavy minerals, which may gradually be carried to the ocean to be reconcentrated in beaches. Likewise, if the ocean encroaches upon an area of monazite-bearing sands, a still further concentration will take place. Seacoast deposits of sand contain a higher percentage of monazite and cover larger areas than known river-bed deposits. The leading commercial sources of monazite sand are beach deposits in Brazil and India.

United States. - The most important domestic deposits of monazite are in the Carolinas, Idaho, and Florida. The Carolina deposits are in an area in the central part of western North Carolina and northwestern South Carolina, comprising about 3,500 square miles and including all or parts of Alexander, Iredell, Caldwell, Catawba, Burke, McDowell, Gaston, Lincoln, Cleveland, Rutherford, and Polk Counties in North Carolina and Cherokee, Laurens, Spartanburg, Greenville, Pickens, Anderson, and Oconee Counties in South Carolina. The Idaho deposits are near Centerville, in the Boise Basin. Monazite is associated with zircon and ilmenite in beach sands at Mineral City, Fla., 4 miles south of Jacksonville Beach. Elsewhere in the United States occurrences of monazite have been reported at various localities in California, Colorado, Connecticut, Indiana, Montana, Nevada, New Mexico, Oregon, South Dakota, Texas, Utah, Virginia, Washington, and Wyoming. Analyses of Carolina monazite follow: 21/

Analyses of samples of monazite from the United States

	1	2	3	4	5	6	7
ThO_2	6.49	1.48	1.22	1.43	2.32	1.19	7.00
Ce_2O_3	31.38	37.26	54.03	2/32.93	1/65.32	3/61.77	34.50
$(La,Di,Yt)_2O_3$.	30.88	31.60		25.54			28.80
P_2O_5	29.28	29.32	23.43	18.38	28.16	26.05	26.00
SiO_2	1.40	.32	1.60	6.40	3.20	1.45	2.00
ZrO_2	....	.....	3.25	.....	.....	.....	.70
TiO_2	....	.....	....	4.67	.61	1.40	.90
Fe_2O_3	....	.....	5.58	7.83	.....	.65	.....
Al_2O_3	....	.....	2.49	1.62	.....	.15	.....
CaO	....	.....	.....	1.20	.....	.....	.70
H_2O	.20	.17	.....	......	.....	.....	.....
Miscellaneous .	....	.....	3/7.74	......	.....	4/6.39	.....
	99.63	100.15	99.34	100.00	99.61	99.05	100.60

1/ Including ZrO_2 and BeO.
2/ Including ZrO_2, BeO, and Ta_2O_5.
3/ Including 4.12 percent $(Cb,Ta)_2O_5$ and 3.62 percent FeO.
4/ Ta_2O_5.

Brazil. - Monazite sand deposits in Brazil include: (1) The beach deposits reserved to the Government; (2) beach deposits lying behind Government reservations; and (3) inland deposits. The bulk of the monazite produced in Brazil is derived from coastal sands in the States of Bahia and Espirito Santo. These beach deposits are the property of the Federal Government for 33 meters inland, measured from the point where the sea waves wash the beach at mean high tide, but this method of marking property is uncertain and has, of course, caused boundary disputes.

21/ Schaller, W. T., Thorium, Zorconium and Rare-Earth Minerals in 1919: U.S. Geol. Survey Mineral Resources of the United States, pt. II, 1919, p. 12.

At a few places along the coast strips of monazite-bearing sands lie directly behind, but not far from, the Government land; these might be worked profitably, but it has been difficult to prove that these sands were not taken from nearby Government land. Along the banks of large rivers, such as the Parahyba, are great quantitites of black sands with traces of monazite. Such deposits have been worked near Sapucaia. Many of the inland deposits cannot be exploited on account of the expense of transportation of the products, as the deposits are many miles from the railroads. Analyses of monazite from Brazil are shown in the following table:22/

Analyses of samples of monazite from Brazil

	1	2	3	4	5	6
ThO_2	9.23	10.05	1.09	6.06	6.50	6.49
Ce_2O_3	31.21	32.14	32.46	62.92	62.10	31.28
$(La,Di)_2O_3$ ..	.....	25.99	36.02			30.88
P_2O_5	28.36	25.51	29.18	28.50	28.46	29.28
SiO_2	10.14	2.63	.....	.75	.64	1.40
ZrO_2	5.74	.60	.....	.....	.....	.....
TiO_2	2.62	.....	.....	.....	.....	.....
Fe_2O_3	4.22	1.79	.61	.97	1.50	.....
Al_2O_3	.32	.84	.....	.10	.08	.....
CaO	1.11	.20	.10	.21	.30	.....
H_2O	.....	.92	.....	.38	.64	.20
Ta_2O_5	1.16	.....	.....	.....	.....	.....
	94.11	100.67	99.46	99.89	100.22	99.53

1/ Monazite from river bed, in large pieces weighing as much as 2 pounds; derived from pegmatite Southern Serra dos Ayamores, Espirito Santo. Freise, F., Ztschr. prakt. Geol., vol. 18, 1910, pp. 123-124.
2/ From river sands of Rio Paraguassir in Bahia, Bandeiro do Mello. Hussak, E., and Reitinger, J., Ztschr. Kryst. Min., vol. 37, pp. 550-579, 1903.
3/ Sand from Bandeirinha, near Diamantina, Mines Geraes. Idem.
4/ Espirito Santo. Johnstone, S. J., Jour. Soc. Chem. Ind., vol. 33, 1914, pp. 55-59.
5/ Alcobaca, Borhia. Idem.
6/ Brazilian monazite. Analysis furnished by F. H. Lee. Gottschalk, A.L.M., Min. and Eng. World, May 15, 1915.

India.23/ - Deposits of monazite sand especially rich in thoria were discovered in 1909 along the sea coast in the State of Travancore in the extreme southwestern part of India. Many of the soils and river sands show monazite,

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22/ Schaller, W. T., work cited, p. 12.
23/ Schaller, W. T., Thorium, Zirconium, and Rare-Earth Minerals in 1919: U.S. Geol. Survey Mineral Resources of the United States, pt. II, 1919, pp. 8-9.

but only certain naturally concentrated deposits along the seacoast are of workable extent. Although there are numerous patches of beach monazite sand in Travancore, only four now are considered of commercial size. The first deposit is on the east coast, about 3 miles north of Cape Comorin. The sand is very fine, and the monazite content is sometimes as high as 20 percent, although the average is much less, depending on wave action. Farther south and immediately north of the cape is the second deposit, much more extensive but of the same general character. The potential yield of these two deposits, together with the periodical accretion due to the action of the waves, is estimated at several thousand tons of commercial monazite.

The third deposit, by far the richest, is on the west coast, immediately north of Cape Comorin. The extreme southern portion is very rich in monazite, reaching 50 percent or more. It has been estimated that 1,200 tons of monazite could be produced annually from this deposit for 20 years.

The fourth deposit is on the west coast about 8 miles south of Trevandrum, the capital of the State, and is not quite as rich as the other three. Numerous other patches which may be of economic importance are interspersed in the regions between these four major fields.

Monazite occurs also in beach sands at Satvaya, on the Orissa coast.[24] In January 1924 the Department of Geological Survey of India undertook a survey of the area, which revealed that the deposits were about 23 miles long, 70 feet wide, and 10 inches thick. The average content of monazite in the sand ranges from 2 to 3 percent (richest sample, 11 percent), compared with the Travancore sands which average 10 percent monazite (richest sample, 60 percent). The thoria content is 7.9 percent compared with 8 to 10 percent for Travancore monazite. Ilmenite is also present in the sand.

Ceylon. - Ceylon is a minor commercial source of monazite. Immediately preceding the World War the Ceylon Government Mining Survey found substantial deposits of monazite sand near Bentota and near Kudremalai on the west coast of Ceylon. Samples of the Bentota sand contained as much as 47 percent monazite and over 4 percent thoria; by concentrating these electromagnetically to eliminate the ilmenite and zircon, a very high grade of monazite can be obtained containing nearly 10 percent of thoria.

Analyses of monazite from India and Ceylon are shown in the following table:[25]

24/ Roy, S. B., Occurrence and Industrial Possibilities of Monazite in the Black Sands on the Orissa Coast: Chem. and Ind., vol. 52, no. 37, Sept. 15, 1933, p. 745.

25/ Schaller, W. T., work cited, p. 13.

Analyses of samples of monazite from India and Ceylon

	1	2	3	4	5	6
ThO_2	10.22	8.65	10.75	10.29	9.49	7.90
Ce_2O_3	31.90	61.73	26.71	27.37	27.15	56.50
$(La,Di)_2O_3$	28.46		31.52	32.27	33.52	
P_2O_5	26.82	26.50	24.61	27.67	26.12	26.80
SiO_2	.90	1.00	2.47	1.03	1.67	1.92
Fe_2O_3	1.50	1.09	1.09	.81	.87	1.40
Al_2O_3	.17	.12	.70	.17	.17	.13
CaO	.20	.13	.85	.41	.45	.27
H_2O	.46	.45	.93	.20	.48	2.20
U_3O_8	.....	.....	.....	.....	.....	2.66
	100.63	99.67	99.63	100.22	99.92	99.78

1/ Sand from Travancore, India.
2/ Isolated from a concentrate from Travancore, India.
3/ From sand from Niriellaganga, Ceylon.
4/ Monazite pebble from Ratnapura, Ceylon.
5/ Monazite pebble from Muladiwanella Durayakanda, Gilimale, Ceylon.
6/ Washed from pegmatite containing 100 grams monazite per metric ton (0.01 percent) from Rifle Range Stream, Moon Plains, Ceylon.

Africa. - Monazite occurs with ilmenite and zircon in beach sands on the coast of Senegal south of Dakar, French West Africa. A deposit of possible commercial size but containing only 4 percent thoria has been reported about 60 miles northeast of Pretoria, and monazite and other rare-earth minerals are said to occur in Swaziland.

Australia. - Certain alluvial deposits in Western Australia[26] contain monazite, cassiterite, and the rare-earth minerals fergusonite, euxenite, and gadolinite. The monazite from Cooglegong is in small pebbles averaging about one fiftieth ounce in weight. A sample of the sand from this district contained 80 percent monazite and yielded 3.46 percent thoria. The monazite sand from the residue obtained by resluicing low-grade alluvial tin ore contained 26 percent monazite. The individual pebbles of monazite yielded a little more than 5 percent thoria.

In South Australia, monazite and fergusonite are present in holdings of the Mount Painter radium field a few miles from Copley and are mined for their radioactive content.

Monazite of low thoria content (0.35 to 4.12 percent) is a frequent associate of tin and tungsten deposits in the New England region, New South Wales. It is also present in beach sands at Coolangatta and Currimbin, in Queensland, and on the west coast of Tasmania, in the vicinity of the Stanley River.

26/ Schaller, W. T., work cited, p. 10.

Norway. - The pegmatites of southern Norway contain large crystals and masses of monazite, which are saved by the feldspar miners and sold as a byproduct. It is reported, however, that the quantity so obtained and sold has never been more than 1 ton for any year.

Monazite has been reported at various localities in Burma; in the Pointe du Bois region, Manitoba, Canada; and in pegmatites at Ishikawa, Iwaki Province, Japan.

Allanite

Next to monazite allanite is the most abundant cerium mineral. It belongs to the epidote group and occurs as an accessory constituent in granite, syenite, diorite, gneiss, limestone, etc. In the United States deposits are known in Colorado, New Jersey, New York, North Carolina, Pennsylvania, Texas, Virginia and Wyoming. Although most of these are of mineralogical interest only, commercial shipments have been made from Wyoming, Virginia, and possibly North Carolina. Allanite is said to occur in rather large amount at Franklin Furnace, N. J., in the granite dike that pierces the ore body of the Trotter mine, and in pegmatitic masses in abandoned iron mines in the vicinity.[27] An interesting occurrence at Baringer Hill, Tex., has been described by Hess.[28]

Cerite

Cerite is the richest known cerium-bearing mineral; the ideal mineral contains 50.7 to 71.8 percent cerium. It was named in honor of the discovery of the minor planet Ceres in 1801.

In the United States cerite has been found in Boulder County, Colo., near Jamestown, but so far as is known only specimen material has been obtained. The best-known occurrences of cerite are in the Bastnäs mines in the Ryddarhyttan district, Sweden. It was there that cerite was first discovered, and 4,465 metric tons of high-grade cerium ore were mined between 1875 and 1888.[29]

Gadolinite

Gadolinite is of interest as a rare-earth mineral because of its yttria content, which, however, sometimes is partly replaced by the oxides of cerium, lanthanum, and didymium. Small quantities of thoria are also present sometimes. Gadolinite usually is found in pegmatites and frequently is associated with allanite and other rare-earth minerals. The earliest discovery of the

27/ Kemp, J. F., The Granite at Mounts Adam and Eve, Warwick, Orange Co., N.Y. and Its Contact Phenomena: New York Academy of Sciences, vol. 7, 1892-94, pp. 638-50.

28/ Hess, Frank L., Minerals of the Rare-Earth Metals at Baringer Hill, Llano County, Texas: U.S. Geol. Surv. Bull. 340 (d), 1907, pp. 286-294.

29/ Geijer, Per, The Cerium Minerals of Bastnäs at Riddarhytten: Sveriges Geologiska Undersökning Årsbok, vol. 14, no. 6, 1920, 24 pp.

mineral in the United States was at Devil's Head Mountain, Douglas County, Colo.; it has also been found in considerable quantity in pegmatites in Aquarius Cliffs, Mohave County, Ariz. The principal domestic source, however, is at Baringer Hill, Llano County, Tex. A double crystal of gadolinite weighing 73 pounds was found there in 1903 when the deposit was being worked by the Nernst Lamp Co., Pittsburgh, Pa.

CHEMICAL SEPARATION

The rare earths are so similar in properties that they tend to enter into similar chemical reactions. The first problem, of course, is to get the mineral into solution. Most of the rare-earth minerals are not readily soluble and accordingly must be powdered very finely. Digestion with hot hydrochloric acid or with hot concentrated sulphuric acid frequently will effect solution, but some minerals require fusion with acid sodium sulphate or digestion with hydrofluoric acid. According to Spencer:[30]

> The minerals cerite, orthite, gadolinite, thorite, and yttrialite yield readily to treatment with hydrochloric acid. Xenotime, yttrotitanite, thorianite, and monazite require sulphuric acid for their decomposition, whilst fergusonite, euxenite, polycrase, samarskite, and yttrotantalite can only be got into solution by fusion with sodium bisulphate or treatment with hydrofluoric acid. It is always wiser when a mineral has to be fused to use sodium bisulphate in preference to potassion bisulphate, because many of the rare-earth sulphates form sparingly soluble double sulphates with potassium sulphate, whereas those that they form with sodium sulphate are much more soluble. When a mineral is digested with hydrofluoric acid, the rare earths are left as insoluble fluorides which must be decomposed by boiling with sulphuric acid in order to obtain a solution.

A scheme for the qualitative separation of the rare earths, starting with a chloride solution which is treated with sodium sulphate, was worked out by Prof. Alfred James and is reproduced in J. F. Spencer's The Metals of the Rare Earths. Some individual chemical characteristics are mentioned in the foregoing descriptions of the elements themselves. In general, however, the separation of the rare earths from each other is tedious and often has to be done repeatedly to remove traces of a residual element. There are two principles of separation, depending upon (1) the variations in basicity and (2) the varying degree of solubility of the different salts in water and other solvents. As the basicity of the rare earths varies from element to element, fractional precipitation of the hydroxides and fractional decomposition by heat of decomposable salts (for example, nitrates) may be utilized. Fractional crystallization of the various salts has been the subject of much careful study, the extent of which perhaps is indicated by the list of compounds that have been suitable for specific separations; this list includes the sulphates, nitrates, oxalates, formates, acetates, ethyl sulphates, and bromates; double nitrates with ammonium, magnesium, bismuth, manganese, or nickel; double sulphates with the alkali metals; acetylacetonates; dimethyl phosphates; and picrates.

30/ Spencer, J. F., The Metals of the Rare Earths: Longmans, Green & Co., London, 1919, p. 22.

USES

Many industrial outlets for the rare earths do not require separation of the individual elements, and for such purposes a rare-earth mixture is employed. This is true in some of the more important fields, such as pyrophoric alloys, flaming-arc carbons, and textile treatment. Some specialized uses, such as the glass industry, pharmaceuticals, etc., require pure cerium, neodymium, or praseodymium compounds. At present "cerium", which usually means the mixture of metals in the rare-earth group, is the principal article of commerce; neodymium and praseodymium are used to some extent for optical glass and art glassware, and 1 or 2 minor uses for lanthanum have been developed. For the other individual members of the group, however, there are no important commercial outlets. The first industrial use for cerium was in gas-mantle manufacture. This is still an important consuming industry, although the percentage of cerium nitrate (1 percent) employed is so small that the actual quantity consumed is not impressive.

Pyrophoric alloys

The leading use for the cerium metals is in the manufacture of pyrophoric alloys, but no figures are available as to the amount consumed in this field. Welsbach, in his research on the rare-earth metals, discovered in 1903 that certain alloys when scratched with a file gave off sparks capable of igniting inflammable gas. Later discoveries and improvements demonstrated that an alloy of cerium metals with iron has the maximum pyrophoric properties.

This alloy, known as "sparking alloy", "misch metal", "ferrocerium", or "pyrophoric alloy", is used in automatic gas-lighting devices, miners' safety lamps, and cigar and cigarette lighters. It was used to a limited extent during the war in star shells, tracer bullets (the friction with the air causing it to flame brightly), and automatic lighters for use in trenches and other places where matches proved impracticable.

Method of manufacture. - The pyrophoric alloys may be made either from metallic cerium or from a mixture of the cerium-earth metals in approximately the following proportions: Cerium, 50 to 75 percent; lanthanum, neodymium, and praseodymium, 25 to 45 percent; and iron, 0.5 to 1 percent.[31]

In the manufacture of pyrophoric alloys the rare-earth residues obtained as a byproduct from monazite sand first are converted to the anhydrous chlorides. The complete dehydration, which is a rather difficult process, is essential in preparing the material for the subsequent steps in its manufacture. The first step is to prepare the material for electrolysis; it has been found that to do this suitably for the continuous commercial production of metallic cerium certain special precautions are necessary. Rather limited ranges of temperature are required for performing efficiently the two processes carried out in the electrolytic cell; these are called, respectively, "separating

31/ United States Tariff Commission, Incandescent Gas-Mantle Industry: Tariff Inf. Surveys C-22, 1921, p. 27.

temperature" and "agglomerating temperature." The electrolyte is prepared preferably by using a solution of a mixture of chlorides of cerium and other rare-earth metals of which cerium is the chief constituent. It should be comparatively free from sulphuric acid and sulphate.[32/]

The purity of this solution is not important, except for the percentages of sulphur and phosphorus compounds and for certain bases such as iron and aluminum compounds, which should be reduced below 3 percent. An excess of cerium oxide will precipitate the iron and aluminum, and calcium chloride (or better, barium chloride) will throw down the sulphates and phosphates.

The solution is then clarified by filtering it hot or settling it, and evaporated to dryness. The preparation of the electrolyte should be carried out so as to obtain the proper surface-tension conditions between the fused electrolyte and the fused metal in the electrolytic bath. An excess of certain impurities, including oxychloride, tends to reduce the surface tension between the metal and electrolyte in the bath and to alter the viscosity, producing an emulsion or colloidal solution of metal in the electrolyte and preventing separation of the metal from the bath.

The electrolysis is done in pots of cast iron high in carbon and silicon, about 8 inches in diameter, and 12 to 18 inches in depth, usually set in brickwork. The heat is applied externally and almost wholly at the bottom of the pot. A small amount of the electrolyte is first put into the pot and nearly fused by a gas heater. The electric current is then turned on and the fusion completed. More electrolyte is added gradually, the contents being brought to the fusion point each time, until the pot is full. Either carbon or graphite anodes are used.

When the mixture of metals comes from the pot it is relatively soft and does not spark easily upon scratching. To make the commercial product, therefore, it is alloyed with about 30 percent of other metals, chiefly iron, and formed into small pieces to make the "flints" used in lighters, etc. The alloy enters into commerce in the form of small sticks or rods, either rectangular or round, and of various lengths, ranging from 200 to 2,000 pieces per pound. Probably the commonest form is a round piece approximately one-eighth inch in diameter and one-eighth inch long; it takes 1,500 to 2,000 pieces of this size to weigh 1 pound.

The manufacture of these small pieces from "misch metal" is difficult and requires delicate and expensive equipment.

Flaming-arc Carbons

Cerium, in the form of the fluoride, is also used extensively in carbons of arc-lamp electrodes. The flaming-arc electric lamp is based on the principle of introducing oxides of rare-earth metals into the carbons to secure an increased flame arc, somewhat as the Welsbach gas mantles increase the luminosity of a gas flame.

32/ Hirsch, Alcan, The American Pyrophoric Alloy Industry: Chem. and Met. Eng., vol. 19, no. 62, Sept. 18, 1918, pp. 510-511.

Calcium chloride and the oxides of iron, titanium, chromium, etc., were first employed with more or less success. To make the carbons (which are commonly of petroleum coke, ground fine and mixed with tar, forced through dies and dried), the metallic oxides either are mixed with the mass or introduced as a core into the enter of the carbon. An increased voltage is required, as the electrodes are drawn farther apart to get a long flame. In some forms, as the magnetite lamp, the lower (positive) electrode is simply a permanent knob of copper, while the upper (negative) electrode carries the mineral salts. Such lamps give a large body of arc or flame and do not burn a crater in the carbon but consume a comparatively flat surface when directly opposed. In one form two carbons are employed, positioned like the sides of a V. The quantity of vapor given off by the flame-arc lamps necessitated an open globe at first, but later it was found possible to draw out the vapor by a draft and enclose the carbons in a suitable glass globe.

Glower Lamps

Before the tungsten filament lamp was introduced the rare-earth metals were used in the Nernst lamp. Instead of carbons it employed what is known as a "glower", - a little rod something over an inch long made principally of the oxide of zirconium, with varying amounts of rare-earth oxides, such as yttria, erbia, thoria, and ceria, mixed with a binding paste and baked into a material resembling porcelain. This rod was provided with platinum terminals. When a current was passed through it, it emitted a soft white light. The life of this form of lamp was 400 to 600 hours; thus it outlasted the arc-lamp carbons, which have a life of only 80 to 175 hours before they have to be replaced.

Incandescent Gas Mantles

One of the earliest commercial uses for the rare earths was in the manufacture of incandescent gas mantles. After several years' study of the rare-earth elements Dr. Carl Auer von Welsbach in 1884 patented the use of a fibrous network composed of the oxides of certain rare-earth metals as a lighting medium. At one time lanthana, zirconia, and ceria were employed for this purpose, but further research revealed the desirability of using a mixture of approximately 99 percent thorium nitrate and 1 percent cerium nitrate. This development (1893) and the subsequent discovery of sufficiently large deposits of the raw material (monazite) gave impetus to an industry which assumed large proportions while electricity was replacinggas in the lighting of homes, offices, factories, and streets. About 1900 a further improvement was made in the form of the inverted mantle, which throws the light downward instead of upward, thereby preventing a shadow.

Method of manufacture. - The gas mantle generally is woven of cotton, ramie, or artificial silk fiber into the form of a hose or tube, bleached, and washed very thoroughly in distilled water to decrease the quantity of mineral matter and to remove grease and other foreign substances.[33] After drying in a current

33/ U.S. Tariff Commission, Incandescent Gas Mantle Industry: Tariff Inf. Survey C-22, 1921, p. 21.

of hot air the fabric is then treated with the "rare-earth" nitrates - a solution containing 25 to 50 percent thorium and cerium nitrate in the proportion of about 98 to 99 parts thorium nitrate to 1 to 2 parts cerium nitrate. Small quantities of beryllium nitrate and magnesium nitrate also are added to the solution to strengthen the ash skeleton. The fabric is then cut into suitable lengths and one end closed and sewed with asbestos thread. After this the mantle is "fixed", a process which strengthens the parts of the mantle subjected to the greatest strain and is accomplished by treating these parts with a thorium solution containing considerable alumina and alkaline earths. If desired, the mantle may then be branded with the manufacturer's trade mark by the use of a mixture containing didymium nitrate, a byproduct of the manufacture of cerium nitrate. After the fabric is dried and shaped it is "burned off", and the nitrates are converted into the oxides by an intense flame. The mantles that are not damaged in heating and have passed inspection for size, shape, and material defects are dipped into a solution of collodion to give them the strength necessary to withstand the shocks of shipping.

The rare-earth nitrates may be replaced in the fixing process by the corresponding acetates or formates, and if of artificial silk the impregnated stocking is treated with ammonia or some volatile alkali such as hydrazine or tetraethyl ammonium hydroxide to produce the hydroxides of thorium and cerium within the fibers. Hydrogen peroxide may also be employed as the precipitant.

Although the optimum effect usually is attained by mixing the thorium and cerium salts in such proportions that the mixed oxides of the mantle consist of 98.8 percent thoria and 1.2 percent ceria, it is customary, owing to the yellow color of the light produced by this amount of ceria in inverted mantles, to reduce the proportion of ceria to 0.5 to 0.7 percent.

Mixtures of ceria and thoria have a catalytic action on the combination of hydrogen and oxygen which reaches a maximum at 450° C. when the mixtures contain 1 percent of ceria. This was the mixture finally used by Welsbach to obtain the highest illuminating power. The activity or, in other words, the illuminating power of pure thoria is the same as that of a mixture containing 9 percent ceria.

It has been considered that the Welsbach mixture represents the best illuminant obtainable from the two oxides thoria and ceria.

<u>Gas-mantle Industry</u>. - Only within recent years have figures become available with respect to sales of incandescent mantles in the United States. Various estimates have been made from time to time which indicate that immediately before the World War the United States consumed approximately 60 million mantles, subsequently decreasing by approximately 50 percent. According to the Bureau of the Census, domestic production of incandescent mantles was valued at $1,595,978 in 1929, $1,135,359 in 1931, and $686,334 in 1933.[34] Imports and exports of incandescent mantles are shown in the following tables.

34/ 1933 value (preliminary) is not strictly comparable with figures for earlier years, as a different schedule was used.

TABLE I. - Incandescent mantles imported for consumption in the United States, 1918-34[1]

Year	Dozens	Value	Year	Dozens	Value
1918	260	$ 316	1927	88,840	$24,947
1919	11	54	1928	72,166	19,769
1920	17,375	13,243	1929	90,892	25,054
1921	51,830	27,001	1930	49,026	15,042
1922	200,659	92,713	1931	18,156	5,270
1923	172,261	65,816	1932	- - -	- - -
1924	171,750	54,507	1933	- - -	- - -
1925	215,404	60,980	1934	54	143
1926	138,743	43,408			

1/ Bureau of Foreign and Domestic Commerce, Foreign Commerce and Navigation of the United States.

TABLE 2. - Domestic exports of incandescent mantles, 1918-34[1]

Year	Value					Total	
	Canada	British India	Hong Kong	Australia	All other	Quantity[2]	Value
						Pounds	
1918	$90,246	$22,043	$7,874	$10,726	$121,395		$252,284
1919	70,654	31,073	6,817	23,308	226,790		358,642
1920	78,359	74,404	16,342	58,125	251,141		478,371
1921	89,599	46,791	2,394	7,538	57,942		204,264
1922	53,155	50,787	925	10,917	49,160	139,640	164,944
1923	42,313	48,277	6,610	10,534	39,102	120,546	146,836
						Dozens	
1924	39,805	47,814	6,603	11,818	48,264	186,928	154,304
1925	35,283	42,946	6,486	18,939	52,239	199,979	155,893
1926	30,401	40,275	5,839	30,149	73,114	230,671	179,778
1927	28,904	46,016	8,405	8,527	53,324	201,890	145,176
1928	36,322	34,849	8,390	26,872	95,842	240,910	202,275
1929	41,828	54,425	12,241	21,902	116,277	316,994	246,673
1930	24,039	30,339	8,736	26,925	89,691	224,237	179,730
1931	26,021	24,963	12,605	16,831	68,036	189,440	148,456
1932	27,798	18,377	6,647	3,991	57,358	144,049	114,671
1933	29,609	13,449	1,395	41	129,489	104,056	84,995
1934						3/117,433	3/92,140

1/ Bureau of Foreign and Domestic Commerce, Foreign Commerce and Navigation of the United States.
2/ Not available prior to 1922
3/ Subject to revision.

Gas-mantle scrap. - In the manufacture of incandescent gas mantles the converting of the thorium and cerium nitrates into oxides by a process known as "burning off" requires considerable skill. From 2 to 3 percent of the upright mantles and 10 to 20 percent of the inverted mantles are damaged in the process. These mantles, together with worn-out mantles collected from gas companies and other large consumers, carry considerable thorium and cerium salts. They are reduced to ashes by a firing process, and the ashes are treated further for the recovery of the valuable thorium and cerium oxides. Prior to the World War the United States imported several thousand dollars worth of gas-mantle scrap annually, but subsequently this source of rare-earth residues has dwindled to insignificant proportions. Except for 30 pounds of scrap valued at $10, imported in 1929, no importations of this material have been recorded since 1922.

Glass Industry

In recent years there has been an increasing trend toward the use of rare-earth compounds in glassware. Cerium is particularly effective in absorbing ultraviolet rays and is employed, either alone or with didymium (neodymium and praseodymium), in spectacle lenses of the Crookes glass or Cruxite type. Didymium itself is not an efficient combination for cutting ultraviolet rays and is present only because of the high cost of didymium-free cerium. However, it does absorb the yellow part of the spectrum and is used commercially in lenses of glassblowers' goggles. It is claimed that didymium glass entirely shuts off the blinding yellow rays produced by incandescent sodium glass, making it possible for workers to see clearly even into the heart of the flame. Some infrared absorption is also obtained by use of cerium and didymium. Additional information relative to the use of rare earths in optical glass is given in the footnote references[35] listed below.

The rare-earth oxides also may be used for tinting art glass, but this market depends somewhat upon the whims of fashion. Cerium glass typically has an attractive golden yellow color, but this may be due to a cerium-titanium combination. Neodymium is used to obtain a special type of purple glass of a peculiar characteristic color not obtainable with other materials. Praseodymium bestows a yellowish-green tint but is too rare and expensive for general use.

Cerium and neodymium are also said to be effective decolorizers in glass, although they have not been used commercially for this purpose in the United States. According to at least one authority (private communication) the virtue of cerium as a decolorizer depends upon its strong oxidizing properties. When cerium oxide is used it oxidizes the iron present to the ferric condition,

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35/ Crookes, William, The Preparation of Eye-Preserving Glass for Spectacles: Phil. Trans. Roy. Soc., London, Ser. A, vol. 214, 1913, pp. 1-25.
Gibson, K. S. and Nicholas, H. J., The Ultraviolet and Visible Transmission of Eye-Protective Glasses: Nat. Bur. Standards Technol. Paper 119, 1918, 60 pp.
Taylor, William C. (to Corning Glass Works), Glass and Batch Therefor: U. S. Patents 1292147-8, Jan. 21, 1919.

in which condition it imparts more of a yellowish cast than green and with the cerium, cobalt is used to neutralize the yellow produced by the oxidizing effect of the cerium on the iron. Possibly the dissimilar results obtainable with cerium may be explained by the differing effects of cerous and ceric compounds.

Textile Treatment

A relatively new use for rare-earth mixtures is as a waterproofing agent and mildew preventive. It is said that treatment with these products provides protection against dampness for textiles (such as canvas fire hose or tents used in moist climates) that are subjected to an unusual amount of moisture.

The treatment of fabrics with aqueous solutions of casein and a salt of a rare-earth metal, such as cerium, thorium, or lanthanum, for mothproofing has been patented,[36] and filter-press cloths may be treated with cerium fluoride to protect them against the corrosive action of acid liquors and vapors.[37]

Alloys

A new light alloy which has been given the name "ceralumin C", has been introduced in England by J. Stone & Co. This contains 0.15 percent cerium, 2.5 percent copper, 1.5 percent nickel, 0.8 percent magnesium, 1.2 percent iron, and 1.2 percent silicon. It is claimed that cerium refines the microstructure and suppresses the formation of the brittle iron-aluminum constituent.[38] Foreign patents have been issued for magnesium alloys, hardened by the addition of as much as 32 percent cerium or cerium metals, for internal-combustion engine pistons; stainless chromium-nickel steel alloys containing up to 10 percent rare-earth metals (or tantalum, columbium, or hafnium); and aluminum alloys containing up to 5 percent lanthanum (alone or in combination with other metals) for making motor pistons and cylinders.

Miscellaneous Uses

Numerous minor uses for cerium and other rare-earth metals have been developed, but they account for very small quantities of these materials and in general represent requirements that could be met as satisfactorily and usually more cheaply by other mineral substances. However, a few of them are worth noting, if only to demonstrate the diversified applications to which the rare earths are adapted. Cerium oxalate and other salts are used medicinally in the treatment of seasickness and nervous disorders. Cerium metal may be used in the laboratory for the reduction of columbium, tantalum,

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36/ Jones, Hilton Ira. Method of Mothproofing Fabrics: U.S. Patent 1688717, Oct. 23, 1928.

37/ Mining Journal (London), Uncommon Metals: Vol. 180, no. 5086, Feb. 11, 1933, p. 15.

38/ Chemical Industries, New Light Alloy: Vol. 35, no. 4, October 1934, p. 323.

etc., as a gas purifier in connection with the manufacture of neon lamps and as a "getter" material (when alloyed with iron, magnesium, or aluminum associated with a nitride and a suboxide of the rare-earth metals.[39]) The oxidizing action of cerium compounds has led to their use in photography, as oxidizing catalysts in organic preparations, and as an ingredient in "driers." Cerium salts have been employed in weighting silk and as mordants in dyeing cotton. As used in the dyeing and tanning of leather the hide decomposes the salts, fixing the cerium in the form of the hydrated oxide; it partly reduces the ceric sulphate or ceric ammonium nitrate, absorbing oxygen in the process, and yields a good quality of leather which has a yellow tint and resists the action of water. Ceric sulphate is used in volumetric analysis.

Yttrium is still more or less of a laboratory curiosity, but a glimpse of its potential usefulness is revealed by scanning the patent literature, which provides for fatty-acid salts of yttrium or other metals for use in the impregnation of textile materials as an insecticide; arc-lamp electrodes made from carbon with iron carbide and at least two carbides of metals "having complementary spectra rich in ultra-violet radiation such as *** yttrium carbides"; acid-resistant alloys comprising 8 to 12 parts yttrium, together with a similar proportion of uranium and larger quantities of tantalum and columbium; and a series of alloys said to exhibit selective radiation at luminous temperatures, which include yttrium and erbium, tantalum and yttrium, molybdenum and yttrium, zirconium and yttrium, and thorium and yttrium.

THE INDUSTRY IN THE UNITED STATES

No rare-earth minerals are mined in the United States except perhaps occasional specimens found at feldspar mines. The only natural raw material used commercially is monazite, all of which is imported, and the domestic industry starts with extraction of the rare earths from this mineral.

Deposits of monazite and other rare-earth minerals are scattered throughout the United States, but only in North and South Carolina, Idaho, and Florida has there been commercial production. Mining began in 1886 in the Brindletown district, Burke County, N. C., and the Carolina deposits accounted for the entire domestic output of monazite until 1903, when production began in Idaho. During the next 7 or 8 years these two States and South Carolina produced more or less regularly. Production ceased entirely from 1911 to 1914, inclusive, and was resumed on a small scale from 1915 through 1917 only. Subsequently the only output reported was a ton of monazite sand recovered in 1925 from a deposit 4 miles south of Jacksonville Beach, Fla.

39/ Miller, Henry (New Process Metals Corporation), Degasifying Devices Such as Thermionic Tubes: U.S. Patent 1864084, June 21, 1932.

During the 10-year period 1900 to 1909 inclusive, when the domestic industry was at its height, the cost of producing monazite in the United States was considerably higher than the cost of importing it from Brazil. The cost of producing 1 ton of domestic concentrates containing 92 to 95 percent monazite was estimated to be approximately $169 at the concentrating plant, whereas Brazilian monazite was laid down at German ports at prices ranging from $95 to $120 per ton (5 percent thoria), a difference of $45 to $70 per short ton. When the Indian monazite first came on the market in 1911 American monazite cost approximately $260 per ton, and Brazilian monazite was being sold on the world markets at approximately $133 per ton. Indian monazite, however, was exported at a price ranging from $120 to $126, or about one half that of the American product, and it carried over 50 percent more thoria (ThO_2) than the American monazite.

Although there was still monazite sand in the United States it could not be produced in competition with foreign monazite, and the industry was forced to close. Even the Brazilian monazite, which is richer in thoria than the American monazite, found competition with the still richer Travancore monazite very difficult. Further declines in price to $50 a ton merely have intensified the situation. Moreover, the relatively low thoria content of monazite produced in the United States has proved an additional handicap in competing with material imported from Brazil and India.

Figures for the production of monazite in the United States from 1893 to 1925 will be found in the world production table on page 35.

No means are available for estimating the extent of the rare-earth industry in the United States. According to the Bureau of the Census, the domestic production of cerium compounds was valued at $239,690 in 1929 and at $403,730 in 1931. No figures are available for 1933, as there were only two producers in that year. The only other index of consumption of cerium products is in the manufacture of incandescent mantles. These figures are given in terms of values, which mean little with respect to the quantity of cerium consumed. Five manufacturers of gas mantles reported production in 1933 - 1 each in Illinois, Kansas, Missouri, New Jersey, and New York.

Pyrophoric alloys are manufactured by only one firm in the United States, consequently no production figures are available.

Late in 1934 the American Treibach Chemical Works, Inc., manufacturer of metallic cerium and products of the rare-metal fields, established a branch plant at Niagara Falls, N.Y. The raw material is purchased cerium chloride. According to published report[40] the plant is to serve as an experimental works for the Treibacher Chemisch Works of Treibach, Austria.

40/ Chemical Industries, New Cerium Source: Vol. 34, no. 5, May 1934, pp. 450-451.

IMPORTS

Before 1909 imports of monazite into the United States were negligible. In that year 35 tons of monazite valued at $8,324 were brought in, and subsequently imports increased more or less steadily, reaching a peak of 2,914 short tons valued at $355,017 in 1917. In general, however, shipments to the United States are erratic and may jump from a fraction of a ton in one year to 1,500 tons or more in the following year. In 1933 and 1934 imports amounted to only 56 short tons and 112 short tons, respectively. Imports of monazite from 1909 to 1934 are shown in the following table.

TABLE 3. - Monazite sand imported for consumption in the United States, 1909-34[1/]

Year	Short tons	Value	Unit value	Year	Short tons	Value	Unit value
1909	35	$8,324	$238	1922	1,733	$210,187	$121
1910	227	39,699	175	1923	127	11,334	89
1911	353	60,542	171	1924	273	18,320	67
1912	278	47,334	170	1925	---	---	---
1913	409	65,848	161	1926	335	23,816	71
1914	385	61,595	160	1927	597	41,029	69
1915	937	161,456	172	1928	442	24,151	55
1916	1,218	188,383	155	1929	577	26,114	45
1917	2,914	355,017	122	1930	---	---	---
1918	1,497	204,661	137	1931	1,698	65,080	38
1919	316	48,768	154	1932	1,569	48,639	31
1920	907	141,528	156	1933	56	1,935	35
1921	(2/)	40	-	1934	112	4,867	43

1/ Bureau of Mines, Mineral Resources of the United States; and Bureau of Foreign and Domestic Commerce, Foreign Commerce and Navigation of the United States.
2/ 50 pounds.

Imports of cerium metal, ferrocerium, and various cerium salts have been reported separately only since 1922. After the passage of the Tariff Act of 1930 imports of cerium fluoride and cerium nitrate were reported together, but in recent years the quantities of these salts and other cerium compounds shipped into the United States from abroad have dwindled to insignificant proportions. Imports from 1922 to 1934, inclusive, are given in the following tables.

TABLE 4. - Imports of cerium metal and of ferrocerium and other cerium alloys, 1922-34[1]

Year	Cerium metal			Ferrocerium and other alloys		
	Pounds	Value	Unit value	Pounds	Value	Unit value
1922[2]	---	---	---	---	---	---
1923	38	$1,031	$27.15	---	---	---
1924	---	---	---	100	$208	$2.08
1925	4	16	4.00	89	185	2.08
1926	20	196	9.80	1	22	22.00
1927	5	35	7.00	71	118	1.66
1928	16	57	3.56	2,085	5,999	2.88
1929	---	---	---	2,524	6,931	2.75
1930	4	13	3.25	861	2,824	3.28
1931	---	---	---	---	---	---
1932	---	---	---	---	---	---
1933	---	---	---	44	232	5.27
1934	---	---	---	---	---	---

1/ U.S. Tariff Commission, Summary of Tariff Information: Sched. 3, 1929, p. 624; Bureau of Foreign and Domestic Commerce, Foreign Commerce and Navigation of the United States.
2/ Sept. 22 to Dec. 31, 1922.

TABLE 5. - Imports of cerium nitrate, cerium fluoride, and other cerium salts, 1922-34 1/

Year	Cerium nitrate			Cerium fluoride			Other cerium salts, not specially provided for		
	Pounds	Value	Unit value	Pounds	Value	Unit value	Pounds	Value	Unit value
1922 2/	---	---	---	54	$ 25	$ 0.46	3	$ 24	$8.00
1923	1,007	$866	$0.86	38,971	3,058	.08	4,821	746	.15
1924	2,258	2,410	1.07	36,650	1,173	.03	83,581	4,361	.05
1925	5,124	5,535	1.08	---	---	---	16,969	1,487	.09
1926	124	181	1.46	---	---	---	11,503	894	.08
1927	20	34	1.70	39,683	2,469	.06	47,155	3,627	.08
1928	102	121	1.18	100	26	.26	100,624	8,047	.08
1929	50	82	1.64	---	---	---	133,935	10,165	.08
1930	3/ 16	3/ 9	.56	4/ 156	4/ 240	1.54	87,948	13,204	.15
1931	---	---	---	---	---	---	397	44	.11
1932	---	---	---	---	---	---	---	---	---
1933	---	---	---	---	---	---	---	---	---
1934	---	---	---	---	---	---	---	---	---

1/ U.S. Tariff Commission, Summary of Tariff Information, Sched. 1, 1929, p. 410; and Bureau of Foreign and Domestic Commerce, Foreign Commerce and Navigation of the United States.
2/ Sept. 22 to Dec. 31, 1922.
3/ Jan. 1 to June 17, 1930.
4/ June 18 to Dec. 31, 1930. Cerium nitrate and cerium fluoride grouped together.

TARIFF

The Tariff Act of 1930 makes the following provisions for rare-earth ores and products:

Provisions of Tariff Act of 1930 for rare earths

Paragraph	Tariff classification	Rates of duty specified and ad valorem
1721	Monazite sand and other thorium ores	Free.
1644	Cerite or cerium ore	Free.
302(p)	Cerium metal	$2 per pound.
302(q)	Ferrocerium and all other cerium alloys	$2 per pound and 25 percent ad valorem.
1534	Gas, kerosene, or alcohol mantles and mantles not specially provided for, treated with chemicals or metallic oxides, wholly or partly manufactured	40 percent ad valorem.
87	Thorium nitrate, thorium oxide, and other salts of thorium not specially provided for, also gas-mantle scrap consisting in chief value of metallic oxides	35 percent ad valorem.

The foregoing provisions are identical with those in the Tariff Act of 1922. However, the 1922 act provided, under paragraph 1577, for "flint, flints, and flint stones, unground" on the free list. As the small pieces of pyrophoric alloy used in pocket lighters and gas lighters were commercially known as flints, importations of these items were held free of duty under paragraph 1577 of the 1922 act rather than dutiable under the provision in the Metals Schedule for "ferrocerium and all other cerium alloys" at $2 per pound and 25 percent ad valorem (Treasury Decision 42686). A rehearing subsequently was granted (Abstract (N) 5888), and pending final decision the Treasury Department issued instructions (C.I.E. 1172) that such flints be classified as dutiable. This ambiguity was removed in writing the Tariff Act of 1930, the provision on the free list being altered to read "natural flints and flint stones."

Before the act of 1922 monazite sand and thorite were dutiable, the rate under the 1913 act being 25 percent of the foreign market value compared with 4 cents per pound under the 1909 act and 6 cents per pound under the act of 1897. "Cerium, cerite, or cerium ore", however, were specifically provided for on the free list of the acts of 1909 and 1913, and under the earlier acts "cerium" was admitted free of duty.

EXPORTS

In the brief period before the discovery of the richer Brazilian deposits, the United States was the leading producer of monazite, supplying not only our own market but substantially all that was consumed in the thorium nitrate industry in Europe. Although no figures are recorded it is understood that from one fourth to one third of the domestic production of monazite sand was exported annually to England and Germany and there used for the manufacture of thorium salts, principally nitrate. However, an export trade could not be maintained against the plentiful supply of cheaper and richer monazite which began to come from Brazil in 1895 and which eventually stifled even the home trade in domestic monazite.

A table of exports of incandescent gas mantles will be found on page 24.

THE INDUSTRY IN FOREIGN COUNTRIES

Monazite production

Prior to the development in 1911 of a monazite-mining industry in India, Brazil was the leading foreign source of supply. The thoria content of high-grade Brazilian monazite concentrates is about 6 percent, which is somewhat lower than that of the Indian ore, although high enough to eliminate the United States as a monazite-producing country. As the market for monazite has been regulated largely by the demand for thoria (for use in incandescent mantles), Indian monazite has tended to supplant the Brazilian product. The decline of the mantle industry and the development of additional outlets for cerium may partly offset this preference, particularly as the ceria and mixed rare-earth contents of Brazilian monazite apparently are as high as in the ore from India.

Brazil. - The mining of monazite sand was begun in Brazil by an American, John Gordon, who realized a considerable profit by shipping the product to Germany as ballast. In 1903 the Brazilian Government decided that the deposits of this mineral along the seacoast belonged to the State and forbade their free exploitation. Bids were let, and the A.C. de Freytas Co., of Hamburg, obtain the rights to exploit these deposits, but later the company formed a partnership with John Gordon, the original shipper of this mineral. They sold their entire output to the German thorium syndicate and in this manner held a partial monopoly over the production of monazite in Brazil.

It was soon found that other manufacturers of thorium products were able to obtain supplies elsewhere and that the whole output from Brazil could not be controlled, so the German syndicate decided to eliminate all competition. Accordingly, in January 1906 the price of thorium nitrate was reduced nearly one half. Sales were made only to consumers, and each consumer was permitted to buy only such quantities as he expected to require for his own needs with no surplus for resale.

The result of this cut in price was to eliminate the smaller manufacturers of thorium nitrate. Although it had little effect upon the larger well-established firms mining their own monazite, the formation of this cartel and the reduction in the price of thorium nitrate had considerable bearing on the export trade of monazite from Brazil. Before 1903 the exports never exceeded 3,400 short tons annually, but after that date the export trade in this mineral increased rapidly until in 1909 it reached its peak - 7,121 tons valued at $704,387. By 1912 Indian monazite, with its higher thoria content, had entered the world market, and exports from Brazil declined. This downward trend has continued, and since 1920 shipments have been less than 500 tons annually.

When the exports of monazite sand were at their peak it was estimated that Germany took about two thirds of the total, the balance going to France, the United States, and England, in amounts that decreased in the order named. In 1926 the United States took almost all of the monazite exported from Brazil; in 1927 and 1928 Germany was the sole purchaser and in 1929 took all but a few tons, which went to the United States; and in 1930 exports, amounting to only 15 metric tons, were shipped to the Netherlands. Information is not available as to the destinations of subsequent shipments.

India. - Monazite from Travancore, India, first appeared on the world markets in 1911, when exports of 932 short tons valued at $117,010 were reported officially. Shipments increased during the next few years, reaching a peak of 2,371 short tons valued at $286,243 in 1918. From 1919 to 1930 exports dropped off considerably, probably as a result of the decline in the gas-mantle trade, but in 1931 (year ended July 31) more than 1,500 short tons of monazite were exported, and subsequent shipments have been unusually heavy. Within the last 3 or 4 years virtually all the monazite imported into the United States has been obtained from India.

Before the World War the monazite output, which was obtained from beach sands between Muttum and Colachel in Travancore, was in the hands of a firm operated under German control. After the outbreak of the war this German interest was soon eliminated, and the industry was placed under the control of British capital. The deposits are worked by Travancore Minerals Co., Ltd., affiliated with Thorium, Ltd., of London, manufacturer of thorium products.

According to available statistics no distinction appears to have been made between production and exports of monazite sand from Travancore before 1919. Exports for later years have been reported as follows:

TABLE 6. - Monazite sand exported from Travancore, India, 1919-33[1/]

Year	Quantity (short tons)	Year	Quantity (short tons)
1919	---	1927	563
1920	1,053	1928	90
1921	---	1929	349
1922	22	1930	---
1923	230	1931	[2/]1,565
1924	112	1932	[2/]1,979
1925	319	1933	[2/]909
1926	388		

1/ Imperial Institute Statistical Summaries, 1919-33.

2/ Year ended July 31.

TABLE 7. - World production of monazite sand, 1893-1933, (in short tons)1/

Year	United States	Brazil2/	India	Ceylon	Total	United States percent of total
1893	65	- - -	- - -	- - -	65	100
1894	273	- - -	- - -	- - -	273	100
1895	787	3,307	- - -	- - -	4,094	19
1896	15	192	- - -	- - -	207	7
1897	22	249	- - -	- - -	271	8
1898	125	2,149	- - -	- - -	2,274	5
1899	175	2,932	- - -	- - -	3,107	6
1900	454	1,633	- - -	- - -	2,087	22
1901	374	1,811	- - -	- - -	2,185	17
1902	401	1,328	- - -	- - -	1,729	23
1903	431	3,636	- - -	- - -	4,067	11
1904	372	5,357	- - -	- - -	5,729	6
1905	672	4,891	- - -	- - -	5,563	12
1906	423	4,797	- - -	- - -	5,220	8
1907	274	4,891	- - -	- - -	5,165	5
1908	211	5,473	- - -	- - -	5,684	4
1909	271	7,121	- - -	- - -	7,392	4
1910	50	5,994	- - -	- - -	6,043	(3/)
1911	- -	4,064	932	- - -	4,996	- -
1912	- -	3,746	1,271	- - -	5,018	- -
1913	- -	1,584	1,383	- - -	2,967	- -
1914	- -	661	1,328	- - -	1,989	- -
1915	18	484	1,241	- - -	1,743	1
1916	19	- - -	1,448	- - -	1,467	1
1917	11	1,252	2,173	- - -	3,436	(3/)
1918	- -	551	2,371	22	2,944	- -
1919	- -	161	2,267	- - -	2,428	- -
1920	- -	1,270	1,838	81	3,189	- -
1921	- -	366	1,411	84	1,861	- -
1922	- -	127	140	112	379	- -
1923	- -	- - -	276	- - -	276	- -
1924	- -	- - -	697	2/28	725	- -
1925	1	22	.05	- - -	198	(3/)
1926	- -	221	72	- - -	293	- -
1927	- -	224	314	4/155	693	- -
1928	- -	112	116	4/112	340	- -
1929	- -	99	202	4/ 85	386	- -
1930	- -	17	16	- - -	33	- -
1931	- -	- - -	100	- - -	100	- -
1932	- -	330	733	- - -	1,063	- -
1933	- -	449	- - -	- - -	449	

1/ Figures compiled from various official sources.
2/ Exports.
3/ Less than 1 percent.
4/ Exports (Mining Jour., London, vol. 171, no. 4970, Nov. 22, 1930, p. 913).

Ceylon. - Production of monazite was undertaken in Ceylon in 1918, when 22 short tons were recovered as a byproduct of gem washing. During the next 10 years fairly substantial shipments were reported, but discrepancies[41/] in available statistics make it difficult to determine the importance of Ceylon as a source of monazite. The thoria content apparently is comparable with that of Indian monazite, and the Government of Ceylon, with the assistance of the Imperial Institute, established monazite works at Induruwa, a few miles from Colombo; however, difficulty was experienced in disposing of the monazite sand recovered, and in the latter part of 1927 it was proposed to abandon the works.[42/]

Available statistics covering world production of monazite from 1893 to 1933, inclusive, are given in table 7.

Rare-Earth Products

Outside of the United States the leading producers of rare-earth products are in Berlin, Paris, and London. In 1930 Deutsche Gasglulicht Auer G. M.b.H., Berlin; Sté. Minière & Industrielle Franco-Bresilienne and Sté. de Produits Chimiques des Terres Rares, both of Paris; and Thorium, Ltd., of London, entered into an agreement[43/] with the Lindsay Light Co. of Chicago, Ill., for the apportionment of world markets for monazite and its derivatives (other than ferrocerium). Under the terms of this agreement the Lindsay Light Co. was required to restrict its sales to the United States and Canada, and the European firms were bound to refrain from exporting thorium or any product derived from monazite sand, except ferrocerium, to the United States. This contract became effective April 9, 1930 and was to continue in effect until March 31, 1940. A further agreement was made between the Lindsay Light Co. and the Travancore Minerals Co., Ltd., under the terms of which the latter company was to furnish monazite to no other firms in the United States than the Lindsay Light Co., this agreement to remain in effect from September 1, 1931 to August 31, 1934. However, on March 5, 1934 the United States Federal Trade Commission ordered[44/] that the Lindsay Light Co. cease and desist from carrying out the terms of the aforementioned contracts and refrain from entering into new agreements of a similar nature.

Germany. - Germany is an important factor in world trade in rare earths, as indicated by the following table covering exports of thorium, cerium, and radium salts from that country.

41/ Exports equivalent to 155 short tons, 112 short tons, and 85 short tons in 1927, 1928, and 1929, respectively, mentioned in Mining Jour. (London), vol. 171, no. 4970, Nov. 22, 1930, p. 913, do not appear in Imperial Inst. Statistical Summary covering those years, although exports amounting to 85 long tons in 1928 are recorded.

42/ Mining Journal (London), Ceylon Monazite Works to be Closed Down: Vol. 158, Sept. 10, 1927, p. 760.

43/ Federal Trade Commission, Complaint, in the Matter of Lindsay Light Co.: Docket 2142, Dec. 22, 1933, 5 pp.

44/ Federal Trade Commission, Order to Cease and Desist, In the Matter of Lindsay Light Co.: Docket 2142, Mar. 5, 1934, 3 pp.

TABLE 8. - Exports of rare earths and their compounds (thorium, cerium, and radium salts, etc.) from Germany, 1927-34

Year	Quantity, metric tons	Value, RM
1927	57.03	619,000
1929	140.15	768,000
1930	75.45	494,000
1931	63.69	402,000
1932	66.01	308,000
1933	83.98	380,000
1934	114.3	377,000

In 1927 the United States was the leading purchaser of German rare-earth products, with the United Kingdom, Japan, and the U.S.S.R. following in decreasing order of importance. In 1929 considerably more than one third of the German exports of rare earths went to the United States, and substantial quantities were shipped to Austria, the United Kingdom, and Japan. Subsequently, Austria and the U.S.S.R. have been the principal markets for German exports; no shipments to the United States have been reported since 1930, and Great Britain's purchases have dropped to inconsequential proportions. Germany's imports of monazite, which amounted to only 2 tons and 1 ton, respectively, in 1932 and 1933, increased to 325 metric tons in 1934. In 1929 ore supplies were obtained almost entirely from Brazil, but this source has been superseded by India. Figures covering world production of gas mantles are not available, but on the basis of exports Germany is by far the leading producer. Exports amounted to 75,514 gross in 1931, 61,313 gross in 1932, and 56,389 gross in 1933.

France. - Little information is available with respect to the rare-earth industry in France. Exports of thorium nitrate and other rare-earth salts amounted to only 193 cwt. in 1931, 614 cwt. in 1932, and 498 cwt. in 1933. France ranks fourth in exports of gas mantles. The rare-earth industry in France is controlled by two firms, one of which has Brazilian connections.

Great Britain. - The leading British producer of rare-earth products is Thorium, Ltd., an affiliate of Travancore Minerals, Inc. In recent years imports of monazite (usually amounting to 150 to 250 long tons) have been obtained almost entirely from British India. Exports of rare earths are not available, but gas mantles are exported in considerably greater quantity (19,733 gross in 1933) than from the United States. Gas mantles also are imported; figures for recent years are 13,874 gross in 1931, 1538 gross in 1932, and 555 gross in 1933. Imports of rare-earth compounds are shown in the following table:

TABLE 9. - Rare-earth compounds imported into the United Kingdom, 1929-33[1/]

Year	Cerium fluoride and other fluorides		Other salts (except $ThNO_3$)		Approximate total value
	Pounds	Value	Pounds	Value	
1929	18,666	£1,749	4,628	£ 879	2,600
1930	7,159	621	2,080	705	1,300
1931	10,183	911	2,779	1,516	2,400
1932	350	54	665	333	400
1933	134	18	1,553	568	600

1/ Trade of the United Kingdom (annual).

Thorium, cerium, and other rare-earth metals (but not the ores and minerals) are dutiable[45/] at 33 1/3 percentum ad valorem under the Safeguarding of (Key) Industries Act of 1921. The act originally in force for 5 years, was extended to 1936. Goods from other parts of the Empire may be brought in free if 25 percent of the value has been acquired in the Empire.

MARKETS AND PRICES

Virtually the only available barometer of the rare-earth industries is the demand for monazite. In the past monazite has been valued chiefly for its thorium content, and for many years during the heyday of gas-mantle manufacture relatively large stocks of residues were accumulating, from which only a small fraction of the cerium metals was extracted, along with the thorium. As these stocks tend to be absorbed for making pyrophoric alloys and other purposes, the trend is toward a demand for monazite for its cerium content. Under these circumstances the Carolina monazite would not be classed as inferior to the Brazilian or Indian product and might eventually command a premium because of its high rare-earth content. It remains to be seen, however, whether the premium could offset the much lower cost of production in Travancore, where labor is so cheap and where the monazite has become essentially a byproduct of the greatly expanded production of ilmenite for making titanium pigments. It is likely that an increased demand for monazite might actually reduce the price by providing an incentive for a better recovery from the rejects of ilmenite production and distributing costs over a larger tonnage.

The price of monazite sand has fluctuated considerably since the World War, in most instances reflecting the declining use of the mineral. During the war the price of monazite sand delivered in New York, exclusive of the duty of 25 percent, ranged from $25 to $40 per unit (20 pounds, or 1 percent of a short ton), or $150 to $240 per ton, based on 6 percent thoria content. Shortly after the war the price was quoted (November 1919) at $27 per unit, or about $162 per ton of the 6-percent (thoria) sand, duty not paid.

45/ Pratt, J. Davidson, Tariffs in the Chemical Industry: Chem. and Ind., vol. 53, July 6, 1934, p. 583.

Before the end of 1925 the price had dropped to $120 per short ton (6 percent ThO_2). After increasing slightly during the latter part of 1928 to $130 per ton, the price fell to $60 a ton during the late fall of 1929 and continued at this level until the middle of 1932. The slightly increased quotation ($63) which then became effective was based upon a minimum thoria content of 8 percent. In June 1933 the price dropped to $50 per ton - the lowest quotation so far recorded in the history of the industry - and remained there until May 1934, when it returned to $60 per ton, the present level.

Quotations for monazite sand at New York, 1920 to 1934, inclusive, are shown in the following table:

TABLE 10. - Prices of monazite, 1920-34 (per short ton, minimum 8 percent thoria)1/

Year	High	Low	Year	High	Low
1920	$252	$180	1928	$130	$120
1921	180	180	1929	130	60
1922	180	120	1930	60	60
1923	160	120	1931	60	60
1924	160	120	1932	63	60
1925	160	120	1933	63	50
1926	120	120	1934	60	50
1927	120	120			

1/ Engineering and Mining Journal, Minimum 6 percent ThO_2 prior to July 1932.

Published quotations are not available for most of the rare-earth products, although prices for small lots may be obtained upon request from chemical manufacturers and mineral dealers.

Cerium hydrate is currently (April 1935) quoted at 75 cents per pound, in drums, f.o.b. sellers' works, and prices for the oxalate are 28 cents per pound, in 300-pound barrels, or 30 cents per pound in 100-pound kegs.

TRADE LISTS

Producers and Dealers

Monazite and other rare-earth minerals:

Industrial Minerals Corporation, 220 Delaware Avenue, Buffalo, N.Y. (monazite & samarskite).
O. P. Babbitt, 281 Molino Street, Long Beach, Calif. (monazite).
Golwynne Magnesite & Magnesia Corporation, 1532 Chrysler Bldg., New York City (Indian monazite).
Foote Mineral Co., 1610 Summer Street, Philadelphia, Pa.
Charles Mohr, Crisman Star Route, Boulder, Colo. (cerite).
L. B. Perkins, Marion, Va. (allanite).
Bradley Johnson, Penland, N. C. (allanite).
Emerald Park Mining & Development Co., Box 374, Buffalo, Wyo. (allanite).

Cerium metal and compounds:

Lindsay-Light Co., Chicago, Ill. (hydrate, nitrate, and oxide).
Maywood Chemical Works, Maywood, N.J. (salts).
Wolff-Alport Chemical Corporation, 1127 Irving Avenue, Brooklyn, N.Y. (hydrate).
Harrison Manufacturing Co., Rahway, N.J. (salts).
Vitro Manufacturing Co., Corliss Station, Pittsburgh, Pa. (hydrate and oxide).
New Process Metals Corporation, 46 Center Street, Newark, N.J. (ferrocerium
E.I. du Pont de Nemours & Co., Inc. (R. & H. Chemicals Dept.), 11th and Orange Streets, Wilmington, Del. (hydrate).
Belmont Smelting & Refining Works, Inc., 320 Belmont Avenue, Brooklyn, N.Y. (metal).
R.T. Vanderbilt Co., Inc., 230 Park Avenue, New York, N.Y. (oxide).
Foote Mineral Co., 1610 Summer Street, Philadelphia, Pa. (carbonate, nitrate).
Mallinckrodt Chemical Works, Second and Mallinckrodt Streets, St. Louis, Mo (nitrate and oxalate).
Merck & Co., Inc., 1935 Kerrigan Road, Rahway, N.J.
Frederick G. Smith Chemical Co., 867 McKinley Avenue, Columbus, Ohio, (nitrate and sulphate).
American Treibach Co., 522 Fifth Ave., New York, N.Y. (cerium metal - plant at Niagara Falls, N.Y.)

Gas Mantles:

Lindsay-Light Co., Chicago, Ill.
Welsbach Co., Gloucester City, N.J.
Coleman Lamp & Stove Co., Wichita, Kans.
General Gas Mantle Co., Camden, N.J.
Erie Manufacturing Co., Erie, Pa.

Possible Buyers

Monazite:

Lindsay-Light Co., Chicago, Ill.
Maywood Chemical Works, Maywood, N.J.
Harrison Manufacturing Co., Rahway, N.J.
A. D. Mackay, 198 Broadway, New York, N.Y.
The Harshaw Chemical Co. of New York, 150 Nassau Street, New York, N.Y.
Varlacoid Chemical Co., 15 Moore Street, New York, N.Y.
National Jewelry & Importing Co., 104 King Street, Winnipeg, Canada.
Blackwell's Metallurgical Works, Ltd., Speke Road Works, Garston, Liverpool, England.

Cerium and other rare-earth compounds:

Varlacoid Chemical Co., 15 Moore Street, New York, N.Y.
A. D. Mackay, 198 Broadway, New York, N.Y.
The Harshaw Chemical Co. of New York, 150 Nassau Street, New York, N.Y.
Welsbach Co., Gloucester City, N.J.
Corning Glass Works, Corning, N.Y.
Pittsburgh Plate Glass Co., 2222 Grant Building, Pittsburgh, Pa.
National Jewelry & Importing Co., 104 King Street, Winnipeg, Canada.

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INFORMATION CIRCULAR

REVIEW OF LITERATURE ON EFFECTS OF BREATHING DUSTS WITH SPECIAL REFERENCE TO SILICOSIS

PART II-B

CHAPTER 4. PREVENTION OF DUST DISEASES
(SECTIONS 3 - 5)

BY

D. HARRINGTON AND SARA J. DAVENPORT

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CONTENTS

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2 Chief, health and safety branch, U. S. Bureau of Mines.

3 Principal translator, U. S. Bureau of Mines.

CHAPTER 4. PREVENTION OF DUST DISEASES (CONT'D)

Section 3. - Engineering Control in the Prevention of Dust Diseases

Hatch (260) made the following pertinent statement regarding the present status of engineering design of dust-control equipment:

> Textbooks on ventilation and engineering handbooks devote little or no space to methods of control of industrial dust, and in the technical journals papers on fundamental engineering design of equipment are conspicuous by their absence. In a recent bibliography of the literature on pneumoconiosis less than 1 percent of the articles dealt with the engineering control of the disease. The science of dust control has not developed beyond the stage of trial and error, and the design of structures for the suppression of dust is based almost entirely upon empirical data together with one or two elementary formulas. The latter were derived from the generalized experience in a limited number of industries such as woodworking, where conditions and requirements are not at all like those, for example, in a sand-pulverizing plant. Wide experience and good judgment are essential to the proper use of the scanty information that has been collected and systematized. Without attempting to minimize the importance of experience in engineering design, it is necessary to point out that most of the past experience obtained in the empirical design of dust-control equipment was not evaluated by means of quantitative studies of the actual reduction in dust. Hence, past experience does not necessarily furnish the proper guide for future design. In fact, recent surveys in certain industries, employing modern methods of investigation, have shown that existing equipment is in many cases inadequate.
>
> Dust control, as practised today, is to some extent the offspring of dust collection, but since they are opposite in purpose, the requirements of one are not necessarily like those of the other. Thus, manufacturers of dust collectors may guarantee collection of 99½ percent and in the production of a commercial powder this is entirely satisfactory, but it has no meaning in the performance of dust-control equipment. It is the escaping dust, not that collected, which is important, and guarantees of performance must be based upon permissible amounts of dust at the breathing zone of the workmen and in the "clean" air discharged from the equipment. For example, assume a safe limit of dustiness in the air discharged from a certain plant to be 1 mg per cubic meter or 0.0000013 grain per cubic foot and assume also a dust loading of 30 grains per cubic foot. Under these conditions, which are not abnormal, the efficiency of dust "collection" must be 99.9987 percent! ***.
>
> The systematic correlation of actual results with the details of design, coupled with an understanding of the physical properties of dust and the laws governing its dispersion and behavior in the air, will provide a body of facts upon which to base the *engineering design of equipment*.

For those who believe that free silica is the only harmful dust the first step toward dust control obviously would be to establish standards of permissible dustiness--as proposed in the preparation of certain codes for the dusty trades--for dusts containing varying amounts of free silica. According to Hatch (146), the maximum allowable rate of intake or standard of permissible dustiness varies with the physical and chemical nature of the dust and the nature of the exposure. A safe value probably exists for every industrial dust, and workers may be exposed to concentrations below the threshold value for long periods without serious damage to lungs or incapacitation. The object of any dust-control program must be to reduce plant dustiness below this figure. Unfortunately, permissible values have not been generally determined, and an estimate of the health hazard in a particular industry therefore must be based upon a careful interpretation of the complete data obtained through occupational and sanitary analyses and medical examination. However, Hatch (146) states that a standard, such as that tentatively set by the United States Public Health Service (10 to 20 million particles per cubic foot of air for granite dust containing 35 percent free silica), in the absence of definite evidence is perhaps justified, provided the figures are not accepted too dogmatically, as once they have been fixed in official codes they attain a sort of sacredness and are removed or changed only with great difficulty. As knowledge of pneumoconiosis is incomplete and methods of medical diagnosis, as well as the technic of dust analysis, are still in the state of development, standardization as to allowable air dustiness would be unfortunate at the present time. Stratton (261) agrees with Hatch that standards of permissible dustiness are too young at the moment to be legislated into State laws or codes, inasmuch as they could be changed only with extreme difficulty upon collection of more complete data; but the use of such standards by individuals, State authorities, and others as a criterion by which to judge an exposure existing either in an industry or a plant he considers advisable and the use by large groups of industries, authorities, or individual technicians would assist in the collection of more complete data, the review of which would prove or disprove the effectiveness of the standard or its accuracy. Unfortunately the natural causative periods of certain industrial diseases are of such duration that experimental control measures must be extended over years to prove their worth; meanwhile the improved measures based upon the existing standards probably can be accepted generally with advantage.

Since no definite, absolutely reliable standards of allowable dustiness are known obviously the aim in the prevention of dust diseases should be elimination of all dust in the atmosphere where people work. Although this aim possibly cannot be realized completely a sincere and continued attempt to attain it unquestionably should result in a gratifying reduction of the dust hazard in industry.

As stated by Harrington (262), the outstanding remedy for the bad situation (in many localities a most distressing one) with respect to dust disease is education--education of workers in the necessity of taking available precautions; of employers in recognizing the seriousness of the situation and in providing devices and methods to reduce or prevent the incidence of disease and, if necessary, in forcing their adoption on the workers; of doctors in correctly diagnosing disease, giving publicity to its prevalence, seriousness,

preventive remedies, etc., and assigning in death certificates dust disease as the cause if such is the case; and of merchants, newspapers, and other influences in the community in trying to prevent the disease rather than to hide its existence.

Instead of recognizing the menace of diseases of various kinds associated with breathing dust and taking advantage of the available methods of combating or preventing them, or at least making a study of the situation with a view to alleviating the harmful conditions and their terrible results, in most instances Harrington (262) finds that--

> There is apparently a concerted effort to hide the facts and to take as few measures as possible toward elimination of the diseases and of the conditions causing them. Miners, especially metal miners, whose health is most directly affected usually refuse to allow themselves to be physically examined previous to or during employment; they frequently oppose the use of wet drills which probably more than anything else will remedy the dangerous dust condition, and in many instances they destroy or try to make ineffective the water attachments to drills; when water is provided to wet down the dust it is generally not used, except when the mine boss forces the worker to it; and mine-workers only too frequently destroy or partly destroy ventilation equipment installed for their safety, comfort, and health. Mine operators or officials usually deny the existence of miners' consumption or other dust disease among employees, yet frequently some of the mine bosses themselves are afflicted by such disease. Suggestions as to remedial methods or equipment, such as sprinkling or the use of water in drilling or in coal cutting, or the use of currents of fresh air to remove dust, are held to be impracticable or are considered the dream of the theorist, even though these methods or devices are in thoroughly successful use in other mines or in other localities. While sometimes the objection to change is due to disinclination or inability to withstand the probable financial outlay, frequently the main obstacle is the fact that mine officials of reactionary type, usually the oldtimer of years of experience and more or less limited education, hates to do anything that he has not been accustomed to doing and repels the idea that dust is or can be harmful.
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> In some instances, after the higher officials of mining companies have spent large sums of money to install equipment with a view to combating dust diseases in mines, the mine bosses who actually oversee the mine operations are not in sympathy with the "new-fangled ideas" , and they make little or no effort to cause the workers to use the preventive methods; sometimes the bosses are in sympathy with the new devices or methods but have not the will power or the "backbone" to force the mineworker to use the new method or device. Doctors, merchants, engineers, business men in general in the community, even those not directly connected with the mines, who should (and frequently do) realize the gravity of the situation as to disease among mineworkers and their families (as tuberculosis frequently intervenes), from motives of self-interest remain quiet. Death certificates of victims of dust diseases are made out as heart disease, or Bright's disease, or almost anything but miners' consumption or bronchitis, and newspaper reports indicate that death was due to a "lingering illness."

Cummins also called attention to the attitude toward dust-preventive measures taken by some miners, according to a statement by the Colliery Guardian (263):

> Dr. Cummins also had hinted at a very important aspect of dust prevention when he stated that he had heard that the miner "will not wear a respirator of any sort." This was partly true. He had even known of cases where the expensive dust receivers had been mishandled and spoiled and more frequently cases where men found it too much trouble to use them. If they acquiesced and allowed this attitude to become a common one the whole campaign against dust would be futile. He would go so far as to say that a second or third offense of this kind should entail dismissal and forfeiture of right to compensation. At the present time, especially, the colliery companies should not be asked to spend more unless every effort were made to insure a full return for their expenditure.

In an article on certain of the legal aspects of silicosis Farrell (264) made the following statement:

> Because sickness from dust exposure is commonly referred to as silicosis, there are many industries having a dust hazard that are not cognizant of the fact and remain in ignorance of it until they are greeted with a summons. Subsequent investigation and a conference with counsel bring home the fact that there is some merit to the suit, and that there is also an industry hazard that is going to prove expensive. The check-up will also often reveal, where there is insurance, that because this hazard was not known to exist there is no coverage for it and that the problem is thus one which the company's lawyers will have to cope with and which the company will have to pay for.

Willson (265) calls attention to the difficult if not alarming position in which employers in dusty trades now find themselves; not having been fully warned or informed until lately of the special dangers of certain dusts, they have exercised merely general care in dust prevention. Anyone not familiar with the exact situation in industry may wonder why employers did not attempt years ago to control the silica-dust hazard. Willson (265) thinks that most employers undoubtedly would have done so if they had been aware of the danger; unfortunately the subject, although under investigation and fairly well understood in scientific circles, was largely unknown to industry, and dust to employers was merely "dust", one kind being thought to be as dangerous as another. According to Willson--

> Most well-intentioned employers may be said to have used "reasonable care" in past years, and this "reasonable care", considering their lack of knowledge, is now their best defense in the damage suits just referred to. However, from now on, with the spread of common, or at least available, knowledge of the peculiar danger of certain dusts, only "special care" will safeguard the interests of employer and workman alike.

Let us now consider what present steps will constitute "special care" where dangerous or poisonous dusts are present; in other words, what shop precautions are now known to be absolutely necessary, based on the knowledge of silicosis just made available to us.

Employers in industries where free silica is present in the atmosphere should constantly be alert and watchful, discounting to the fullest extent every possibility of danger. Employers should not conclude that they have entirely eliminated danger of silicosis, or of any type of pneumonoconiosis, simply because the air is seemingly free from dust. It should be borne in mind that the particles which do the most harm are invisible and that they remain long in suspension in the air. It has been estimated that dust particles 1 micron in diameter require 8 hours to fall 6 feet in still air and that even larger particles, 5 microns in diameter, require nearly an hour to fall to the floor from the height of a man. Particles remaining so long in suspension in room atmosphere continue the danger throughout the entire working day; hence the urgency of postponing sweeping and dusting until work for the day has ceased. Often dust is thrown back into the air during these operations. Furthermore, dust of dangerous character may be so extremely fine in grain as never to settle at all but remain in suspension indefinitely.***.

Getting workmen to wear safety devices requires the same mental attitude on the part of the management that a good salesman must have when he goes out to capture a difficult new account. If the management is not convinced that protective devices must be employed at all times, and if they, in turn, cannot convince their shop superintendents and foremen that such devices are necessary, then they cannot but blame themselves if workmen fail to manifest a good spirit toward self-protection. For psychological as well as for protective reasons, shop superintendents, as well as foremen, when approaching dusty operations should invariably wear their respirators, and even visitors to plants should not be permitted to enter dusty departments without wearing respirators. In this way workmen can finally be convinced that the management truly believes in full-time protection. For best results every one concerned should be willing to live up to the rules of the shop, without exception. In this work any weakening on the part of the management is fatal.

The most erroneous and expensive policy any employer can adopt is to minimize to his workmen the dangers of free silica dust; no true observance of dust protection can be expected from the workman unless he is fully acquainted with the dangers of his occupation.

It cannot be assumed that workmen in our American factories are so unintelligent as to wish to ignore dangers about which they have been fully informed. Rather they, like the rest of us, are apt to scoff at occasional warnings, preferring to doubt that danger exists. It is essential, then, that the management should know the truth first of all. Supervisors should be told the whole story, and workmen severally and individually, in season and out of season, week in and week out, should be educated, warned, and even cajoled into full observance of the rules. Anything short of this will never

bring about a decrease in silicosis where free silica is handled. Unless this end is attained the burden of liability expense, whether determined by civil suit or by workmen's compensation laws, will grow progressively heavier as statistics accumulate.

Where this has not already been done it would be wise, as an additional precaution, to organize shop committees in dusty plants. These committees, selected from management, supervision, and common labor, should make periodic inspections of their respective plants and draw up recommendations for improvement in equipment and shop maintenance. Recommendations made by shop committees so constituted are generally more convincing to workmen than orders issued directly from headquarters, and considering the situation as to liability, no step, however radical, is to be overlooked or neglected. Liability cannot be lessened by having workmen sign waivers or by any other means than protection and prevention.

In an article published in the June 1934 issue of Industrial Medicine McCann (266), professor of medicine in the University of Rochester, described the hurricanelike suddenness with which a deluge of common-law suits for negligence fell upon various industrial employers in Rochester, N.Y. In the beginning these suits alleged that the injury was due to silicosis; the indefiniteness of the diagnosis of silicosis is shown by the results of the investigation by the University of Rochester for the industries concerned. It was learned that quite a number of different diseases produce changes in the lungs which in X-ray pictures resemble closely the early stages of silicosis. The use of this information by the defense led to broader claims for injury--"silicosis became pneumoconiosis, and this in turn became fibrosis and disease of both lungs and upper respiratory passages due to inhalation of dust." Although designating the prosecution of such claims as a "rapidly growing racket", McCann (266) stated:

> Preliminary dust counts showed that in a number of plants dangerous quantitites of dust were in the air, in spite of the fact that operations were proceeding at a mere fraction of normal.
>
> The results of the X-ray survey so far have likewise been disturbing.***.
>
> I feel sure that the cost of eliminating dust will be far less than the cost of insuring against the hazards of dust. Money should be invested now in research in dust prevention and dust removal. I cannot believe that inventive genius will fail to respond to this dire necessity. Different industries will have to solve this problem in different ways, but no one can doubt that ways can and will be found and that they will be less expensive than paying for lawsuits or awards.

Dust Control in the Mining Industry

The first systematic study of silicosis among miners was undertaken in South Africa, and methods of control of the dust hazard in the mines of that country have been an example for other mining districts of the world. The awakening to the seriousness of the hazard in the mines of South Africa came

in 1901, when a report by the government mining engineer disclosed an annual death rate of 73 per 1,000 among the miners (81). The report of the first Miners' Phthisis Commission, issued in 1903, made certain general recommendations regarding dust prevention--particularly in development work--ventilation, underground sanitation, and provision of "change houses" for miners. A phrase in the Report of the Transvaal Medical Society (81), "dry mining must as far as practicable become wet mining", reflected contemporary opinion and indicated the main direction of dust-prevention measures on the Rand to the present time.

As a result of the Commission's work (81), regulations issued in 1904 and 1905 required that sprays or jets be used with machine drills, that broken ground be damped in development places, and that blasting operations be arranged to avoid exposure to dust; return to working places was prohibited after blasting until the air was clear, and efficient ventilation was to be provided.

Unfortunately no effective means of enforcing these measures were prescribed, and the inborn conservatism of the miners, who have more or less universally disliked innovations in traditional ways of working, did not help matters. Unquestionably conditions were much improved but not enough to produce very substantial results. The idea persisted that the main cause of the trouble was rock drilling with machines and that rock-drill machineworkers in mines were virtually the only sufferers; the very dangerous conditions produced by the widespread dissemination of blasting dust received inadequate attention.

In 1907 a second Commission was appointed by the Government of the Transvaal. Medical evidence submitted to it by Macaulay and Irvine (81) indicated that the local mortality from phthisis during 1905-07 had been approximately six times higher among underground workers than among other males on the Rand. A revised code of mining regulations based upon recommendations of the Commission was promulgated in 1911, instituting many improvements. Chief of these were the introduction of qualitative tests of ventilation and the requirement of mechanical appliances where natural ventilation was inadequate. As before, the use of water jet or spray was required in machine-drilling, and the responsibility of the manager to maintain an adequate and constant supply of clean water for use of these appliances and for damping down working faces and broken rock in ends and stopes was tightened. Responsibility was placed on the sectional officials to insure proper observance of preventive regulations. The result was that the use of water for allaying dust underground became much more general. In 1913 additional provisions introduced into the existing regulation required that an adequate supply of water be provided throughout each mine by a system of pipes. This cardinal requirement led to much greater efficiency and uniformity in the provision of water for use with sprays and jets, for water blasts, and for wetting working places and broken ground.

Regular determinations of the dust in mine air were begun by one mining group in 1911, and the first systematic dust survey of all mines was conducted by the Prevention Committee in 1913-14 (81).

The February 24, 1934, issue of the South African Mining and Engineering Journal (269) summarizes the dust-reduction methods used in South African mines as follows:

1. Wet drilling.- Water is kept in the hole throughout the whole period of drilling, whether by hand or machine. This has been compulsory for the past 12 years.

2. Water-spraying (by water blast).- This is done especially after blasting; all likely dust-making surfaces are kept wet.

3. Filtration.- Flannel filters are used at the ore bins (on the crushers) and in other places. These need changing every 2 hours in some cases.

4. Time.- An adequate period is enforced between blasting and return to the working face; this allows much of the dust to settle.

5. Sampling.- The air is systematically sampled by the konimeter, its dust content examined and recorded.

6. Ventilation.- A continuous supply of pure (filtered and cooled where necessary) air is pumped to all working places underground and arrangements made for the proper removal of foul air.

7. Wearing of masks.- Occasionally individual officials wear a mask containing cotton wool or gauze.

The following suggestions were made to further diminish the dust danger in South African mines (267):

1. Limitation of drilling to those parts of the face which contain least sericite (the fibrous death-dealing mineral).

2. Comparison of results under similar conditions of wet and dry mining.

3. Discovery of explosives that blast out lumps of rock, rather than shatter it into small fragments and manufacture dust.

4. Removal of more dust by way of the upcast ventilating shaft.

5. Addition of proportion of soap, naphthaline, or other substance to water for washing down after blasting in order to increase its dust-catching powers.

6. Development of a new technic for konimeters (dust measuring instrument) so that the proportions of sericite in mine air can be ascertained.

7. Increase in the number and efficiency of dust traps and filters.

8. Provision of suitable light masks to which air free from dust, oil, and poisonous gases can be supplied by means of flexible long tubes to the air-pressure pipes now used for pneumatic drills or from light portable cylinders containing compressed air, so that underground air is never inhaled.

The following possible lines of attack have also been mentioned (267):

1. The discovery of a solvent for sericite.

2. The use of an oily solution for the inside of the nose with a strong, simple application that can be carried and frequently used.

3. The daily removal of all dust (by vacuum cleaners) from clothing worn underground.

4. The use of snuff for compulsory sneezing.

The statement has been made (155) that preventive methods, such as wet drilling and water-spraying, have not been successful in depositing the finest and most dangerous dust and in preventing the incidence of silicosis. It has been suggested (155) that the problem of prevention in the South African gold mines could be solved by using an apparatus (not a respirator of usual type) that would enable the miners to breathe directly the fresh uncontaminated surface atmosphere already available through the air-pressure pipes supplying the pneumatic drills.

According to the Colliery Guardian (268), water at best is a poor layer of the fine dust which is most harmful, whether silica or chiefly sericite; but since water has been used konimeter estimates show that the dust in mine air has been reduced considerably, and the rate of production of silicosis has also decreased.

The South African Mining and Engineering Journal (269) states that gratifying progress continues to be made by the Chamber of Mines in its campaign for the prevention of phthisis through the laying of ordinary dust. Exhaustive tabulations show that today the standard of purity in underground air continues to rise. Between 1933 and 1934 an improvement of 1 mg per cubic meter was reported. An expert said that "actually the standard of dust purity at the bottom of many of our mine shafts has been shown to be substantially higher than that of Johannesburg streets on a windy day." If silicosis is caused by the inhalation of dust the removal of dust will remove the cause, which means, according to Bateman (270), ventilation and lots of it and, where possible, the wetting down of dusty places. He states that ventilation and water will remove the visible dust from the air, but it is not the visible dust that causes the damage but the dust that ranges between ½ and 5 microns, which is very difficult to remove; the quantity in the air can be determined only by some method of sampling. However, he considers it a mistake to have either the type of sampling apparatus or the permissible dust count defined by law; "this," he says, "may be all right on the Rand in South Africa where conditions are more or less standard, but it is not advisable in the United States or Canada where conditions vary so greatly."

Sources of Dusts in Mine Air

The main sources of dust in metal-mine air in the order of importance are (262): Dry drilling of holes for blasting (dry drilling of holes pointed upward, especially from about 70° vertical, is, in general, the worst); blasting; shoveling or "mucking" very fine dry material at the working face, which is usually poorly ventilated; loading cars from chutes; dumping loaded cars into chutes; and timbering. Dry crushing and other occupations in metal-mine mills are also dangerously dusty. One such mill in Nevada caused so many fatalities that the death certificates of the victims showed the cause of death as dust from this mill, the disease being called by the name of the mill.

The most dangerously dusty occupation in coal mines (262) is the cutting of dry coal by mining machines. Electrical cutting machines usually produce more dust than compressed-air machines. Undercutting machines send enormous amounts of very fine dust into the surrounding air; shearing, centercutting, or overcutting machines produce even more dust than undercutting machines. Blasting throws large quantities of very fine dust into the air; shoveling dry coal into cars and loading dry coal into cars from chutes are also very dusty coal-mining occupations, particularly when pillars are being extracted. Some coal miners drill overhead holes into shale or other rock roof to prepare for "brushing" shots to increase the height of low coal workings; when these holes are drilled dry by breast or rachet augers and the cuttings allowed to fall through the air past the face of the driller the danger from dust inhalation is great; similar use of dry jackhammer-type compressed-air drills either in coal or in the rock, shale, or clay of the roof or floor gives such dusty air that the driller and all persons in his immediate vicinity inhale enormous quantities of very fine, more or less insoluble dust. In dry coalmine workings enormous amounts of a very finely divided mixture of coal and rock or shale dust frequently collect on haulage or travel roads and present a serious hazard if the circulation of air is sluggish or practically nonexistent.

There is probably not one dry mine in the United States, coal or metal (262), where the average air dustiness of working places is as low as 5 mg per cubic meter of air (the South African standard) or 10 mg per cubic meter of air (the standard set by Higgins and Lanza in their study of miners' consumption in the Joplin (Mo.) district in 1915). In general, the average air dustiness of working places in dry metal mines in the United States (262) is above 20 mg per cubic meter of air and in many, above 50. Shoveling coal in one mine in a confined, poorly ventilated very dry place gave approximately 8 billion particles per cubic meter of air; numerous places in the same mine where men were shoveling gave 1 to 5 billion particles per cubic meter of air. In another coal mine where an undercutting machine was cutting in coal without the use of water on the cutting chain the air breathed by the workers contained nearly 5 billion particles per cubic meter of air; over 4 billion of these were less than 10 microns in size, and hence were probably breathed directly into the lungs. In these instances much of the 8-hour shift was spent in breathing such air, and it is not surprising that physical examination showed many cases of miners' consumption or so-called "asthma" among these coal miners (262).

The following conclusions were reached by the United States Bureau of Mines (271) from a study of sources of dust in 15 representative coal mines in 6 coal-mining States:

1. Jackhammer-drilling produced the greatest concentrations of dust of any of the mine operations, 10 times as much as any of the others, and the other dust-producing operations arranged in decreasing order of concentration were electric drilling, undercutting coal by dry methods, auger-drilling by hand, loading coal, undercutting coal with the application of water on cutter bar of mining machines, simultaneous pick-mining and loading coal, loading rock, haulage, and finally, pick-mining.

2. The largest total amount of dust was raised by dry undercutting.

3. Undercutting coal without the use of water on the cutter bar raised the greatest concentration of dust of any of the common mine operations; loading coal ranked next and haulage last.

The United States Public Health Service reported (180) the following results of 80 dust determinations--60 underground and 20 in the breaker--made at an anthracite mine in the United States in 1926:

The miners and mine laborers, who made up two thirds of the total force employed in the anthracite mine, were exposed at times to an exceptionally high concentration of dust, namely, almost 1 billion particles per cubic foot of air. The average, however, which takes into account the time spent under different conditions of dustiness, was much less, being 124 million particles per cubic foot of air.

In addition to the miners and their helpers, two other groups of underground workers were exposed to a relatively large amount of dust: (a) The rockworkers and (b) the runners and drivers, who have to enter the miners' workplaces at times when the air is particularly dusty. Considering the time spent in the dusty and relatively nondusty parts of the mine, one may estimate that the average exposure of the runners and drivers was about 36 million particles of dust per cubic foot of air. The remainder of the underground workers were exposed to a relatively small quantity of dust. Aboveground it was found that the men in certain occupations, namely, the coal dumpers, jugmen, and slate pickers, were exposed to nearly as much dust as the coal miners. At the breaker the dust is practically the same as that in the mines.

The rockworkers are the only ones exposed to a dust containing a high percentage of quartz (31 percent). Since the average concentration of dust was 82 million particles per cubic foot of air, it is obvious on the basis of previous experience that these workers have a severe hazard. Small numbers and lack of occupational continuity made specific study of this group impossible.

In addition to counting the dust produced by various mining operations, the extent of the hazard may be determined by physical examination of the mineworkers and correlation of the results with their occupational history. The results of the study made at Picher, Okla. (89), showed the following connection between dust exposure (occupation) and dust disease:

All examined were divided into two groups: (1) Those exposed to large amounts of dust (those employed at the face) and (2) those exposed to relatively small amounts (those away from the face). Dust investigations of the mines show that the bulk of dust is raised at the face.

In the order of exposure to the dust hazard, the men at the face include shovelers' helpers, shovelers, drill helpers, machinemen, trackmen, roof trimmers, powdermen, shovel bosses, and ground bosses. This group included 3,051 men (61.1 percent of the 4,992 men). Of the 3,051 men 296 (5.9 percent) were not required to be at the face all of the time. These were ground bosses, roof trimmers, and trackmen. A tabulation of the men working at the face, including the 3 groups last named, shows that 38 percent have silicosis, silicosis with tuberculosis, or tuberculosis uncomplicated.

The men working away from the face include screenmen, mule drivers, hookers, hoistmen, bumpers, trammers, roustabouts, ropemen, pumpmen, electricians, safety engineers, superintendents, and millmen. At the time of the examinations 1,941 men (38.9 percent of the total 4,992) were employed in these occupations. Of this second group 24.9 percent had silicosis, silicosis with tuberculosis, or tuberculosis uncomplicated, as compared with 38 percent for the first group.

The group of men not employed at the face includes the hoistmen, who are, however, exposed to considerable dust arising from the arrangement of hoisting machinery. There were 270 hoistmen (5.4 percent of the 4,992); of these 101 (37.4 percent) had silicosis or tuberculosis or both diseases. Excluding hoistmen, the men employed away from the face showed only 19.7 percent with silicosis or tuberculosis or both. Many in this group are old miners who, because of their experience, are placed at this work. Some are physically unable to do facework and are forced to less remunerative positions away from the face.

A study of the past occupations of the second group shows that 274 had worked at the face 1 to 30 years, an average of 9.9 years for the group. If these men, who had formerly worked at the face, are considered as really belonging in the first group the data show that 43 percent of the facemen ultimately contracted silicosis, as compared with 5.6 percent of the men who had worked the entire time away from the face (exclusive of hoistmen). A study of the occupations of the men before they began work in metal mines shows that 0.8 percent were employed in dusty occupations, such as tool-dressing, concrete-dressing, ore-loading, or foundrywork. The silicotic miners who worked away from the face had been employed in the mines an average of 19.1 years; those with silicosis and tuberculosis, 15.5 years; and those with tuberculosis (not complicated with silicosis), 13 years.

Fifty-two men in the group who had not worked at the face had doubtful histories; although they are included in the tabulation and account for approximately half of the group with silicosis and tuberculosis they are believed to have been facemen formerly. With these men included, the data show that the men working at the face are approximately eight times more liable to contract silicosis than those working away from the face.

A study of the control of drill dust in the mining industry in Germany (272) revealed that the dust burden and danger is not so great in the majority of German mines as in some other countries. Relatively the greatest dust hazard is in machine-drilling with compressed air in metal mines and in exploration and preparatory work in dry, hard country rock of the hard-coal mines, because the miner must breathe directly large amounts of injurious dust at the place of origin. The report (272) states that the dust caused by drilling is thrown into the air and dispersed by the circulation of the air and the air movement caused by the operations and by the exhaust from the compressed-air apparatus. There is an extensive sifting of the rock dust in moving air according to particle size or, more exactly, according to uniformity. The greatest part of the drill dust from the ordinary spiral or twist drill issues quietly from the mouth of the drillhole and runs to the ground in a moderately coarse stream; this stream of coarse material comprises more than 90 percent by weight of the entire drill dust, falls without developing much dust, and causes virtually no trouble for the worker. Part of the drill dust measurable by weight, however, is circulated immediately through the atmosphere by moving air and carried a short distance but loses its cloud-forming ability and soon falls, according to the velocity of the air stream, several meters from the drillhole. The medium-fine drill dust floats in the air as actual dust but on account of its inability to remain in suspension is not carried into the other mining rooms; it is seen as a thick dust cloud before very heavily coated places, settles in a crust on rock piles, or is deposited on the floor and timbers and covers the tools and bodies of the workers. This dust is especially severe at the mine face and by irritation of the mucous membranes of the eyes and the respiratory organs causes catarrhal inflammation, coughing, and colds. However, it is not the worst enemy. Really dangerous are the weighable amounts of the finest dust, which rises from the drillhole at the face as fine smoke and remains in suspension for hours. This almost imperceptible dust cloud, often forming considerably less than 10 percent of the total dust originated by drilling, diffuses even in motionless mine air into the general air stream and is carried through the entire mine.

Methods of Controlling Dust Production in Mines

After many years of observation Harrington (273) has reached the following conclusions regarding remedial dust measures for metal mines:

1. In mining it appears that ventilation, fire protection and prevention, health, safety, and efficiency are very closely interlocked.

2. There is at least equal reason for providing adequate ventilation for most metal mines as for providing ventilation for coal mines.

3. Metal mines rarely, if ever, make provision for ventilation until forced to do so by some untoward condition or occurrence; coal mines, on the other hand, almost universally provide for ventilation.

4. Efficient ventilation of metal mines consists in supplying at all times such volume of circulating air at places where men work as will enable the worker to exert himself in comfort at maximum physical capacity without endangering his health.

5. Many, probably most, operating officials of metal mines are ignorant of the principles of air circulation; this is true of those technically educated as well as of those without technical training.

6. Workers in metal mines, including shift and other bosses, should be educated to respect ventilating devices, such as doors, regulators, overcasts, brattices, fans, etc., as coal miners do and to become as familiar with those devices as coal miners are. Many present-day reactionary metal miners and bosses consider ventilation a useless fad and obstruct rather than aid ventilation improvements.

7. Ventilation should be under definite, constant supervision, and preferably the person incharge should report to the highest officials, as many local officials in metal mines are not in sympathy with ventilation betterments.

8. Each mine should be ventilated wholly within itself; interventilation of mines is likely to be dangerous, inefficient, and unsatisfactory.

9. Workers in many metal mines are much less healthy than workers in coal mines, due largely to the superior ventilation of the collieries.

10. Miners' consumption, the scourge of metal miners, is caused primarily by breathing very fine particles of certain mineral dusts and especially of siliceous dust. Over 50 percent of mineral-producing mines are working in more or less siliceous material and, through lack of ventilation, are giving this dangerous dust maximum opportunity to exercise its harmfulness.

11. The best remedy for the dust menace in mines, other than preventing its formation, is the universal coursing of currents of air to remove the dust, as it has been proved that the very fine, most dangerous dust in metal mines remains suspended in still air several hours.

12. Metal-mine dust, acting through miners' consumption, lead poisoning, bronchitis, etc., is the chief instrumentality in causing perhaps more deaths annually among the approximately 200,000 metal miners in North America than coal dust causes to the approximately 700,000 coal miners through explosions.

13. It is fairly well-established that miners' consumption is caused chiefly by siliceous dust, but it is probable that any kind of dust in large quantities in finely divided form in mine air will prove harmful to workers

ultimately. Investigations in metal mines of the United States indicate that the air of mines so far studied is from 7 to 40 times as dusty as in South African gold mines.

14. Intake air of metal mines is frequently rendered dusty by having a crusher house or other dust producer near the collar of the intake air shaft or by having ore skips or cars or ore-dumping places in intake air passages without the slightest attempt to allay the dust produced or to prevent its entering the mine.

15. The dustiest, most unhealthful occupation underground is dry drilling, and the average dust content of air in places where this work is done in 5 large mines in various parts of the United States was 205 mg per cubic meter of air; yet for similar work in South African mines, but using available precautions against dust formation, the dust content of air is said to be less than 5 mg per cubic meter of air.

16. Although there are regulations in many of the mines of the United States to prevent dust formation in drilling these regulations are not always lived up to. Miners, although recognizing the danger from dust, often prefer to take the risk rather than endure the slight discomfort of extra trouble of using the precautionary methods or devices; and mine and State officials appear to feel that, unless the miner will willingly aid in protecting himself, they cannot force him to protect his own health and incidentally that of his family. Dust-prevention devices of proved success, such as present-day self-rotating wet stopers, should entirely supplant dry drills, and their use should be enforced upon both miners and operators in metal mines, as there is absolutely no valid excuse for dry drilling in present-day metal mining except in a very few instances. To date, no workable device is available for removing dust in dry drilling in underground mines.

17. Spraying devices available to reduce dust while drilling may be effective if used intelligently; on the other hand, they may even intensify the air dustiness if used without intelligence and unfortunately, the latter is generally the case. Efficient water drills are now available for all purposes in metal mining (including efficient wet stopers for upper holes), and dry drilling should be prohibited.

18. Some metal mines with high dust production under certain conditions at working faces have comparatively low dust content of the air in these places at other times and have low average dust content of all places due to efficiency of ventilating currents, especially at working places. Significantly, these mines appear to be singularly free of miners' consumption or other diseases, yet the employees work at top speed and the material handled is highly siliceous.

19. The use of poorly placed compressed-air hose blowers at working faces frequently intensifies air dustiness by allowing high-velocity compressed-air streams to pass through dry, loose, finely divided ore or other material being drilled, shoveled, or otherwise handled, and thus forcing workers to breathe this air highly impregnated with dangerous fine dust.

20. While finely divided dust in mines is probably the chief cause of miners' consumption, it is now recognized that there may be other factors of almost equal influence, such as high temperatures and humidities, harmful gases, and lack of air movement; all of these defects are readily remedied by ventilation.

The following comparison of mining practice in the United States with that in South Africa is interesting (262). In the South African mines on the Rand about the same number of miners are employed as in all of the metal mines of the United States, and the problem of dust disease is not "side-stepped" as it is and has been in the United States. About 30 or 35 years ago a very complete health study was made, revealing the extreme seriousness of dust disease among the workers and resulting in the adoption of drastic laws and regulations, which apparently are rigidly enforced and which are said to have resulted in a marked decrease in the incidence of the disease and of the death rate from it. Mines with 1,000 men or more underground must have employees especially detailed on dust and ventilation work, whereas only a few of the metal mines or tunnels in the United States even consider dust or ventilation. South African mines must have running water, under a minimum pressure of 30 pounds a square inch in not less than 1-inch pipe within 50 feet of working places; very few of the metal mines of this country, on the other hand, have water available near working faces. South African mines must also have water blasts and sprays at or near all working faces; few, if any, American metal mines have them. All drilling in South Africa must be done with drills through which water flows into the hole to prevent formation of dust; many miners and mine officials of this country insist that "it can't be done", especially in the drilling of upper holes. In South Africa all blasting must be done after the men are out of the mine, the region where blasting is done must be wet down thoroughly both before and after blasting, and men must not enter until 30 minutes have elapsed after blasting; in most mines of the United States blasting may be done at any time--in general, no provision is made to wet places at any time before or after blasting, and men return to blasted places whenever they are ready. South African mine travelways and ore or rock piles must be sprinkled enough to prevent dust; very few metal mines or tunneling operations in the United States sprinkle, and most of the operators say sprinkling is impracticable. In South African mines old workings must be closed, air currents must be split, air dustiness and chemical composition must be determined periodically by sampling and analysis, shift bosses must take daily record of the use of water against dust, and numerous other preventive regulations practically unknown in the United States are in effect and said to be strictly enforced.

An examination of the amount of air driven through coal mines in France and the dust content of the air as it emerges from the pits indicates that ventilation provides excellent prophylaxis against pneumoconiosis (274). The dust is composed of fine particles of coal, silicates, and crystalline silica; the silica constitutes 10 to 60 percent of the total. The density in the workings is seldom less than 6 mg per cubic meter and may be as much as 500 mg. Even the less favored miners get 100 liters of fresh air a second.

Education is badly needed among coal miners (262). The coal-mining public, instead of "standing pat" and referring to out-of-date and misleading foreign statistics that coal dust is harmless to health or is even healthful, should make an impartial but strict study of dust conditions in coal mines (anthracite, bituminous, and lignite), paying particular attention to X-ray examination of the chest; coal-camp doctors who have direct knowledge of the harmfulness of coal dust to underground workers, especially those working on mining machines, should write technical articles describing the situation; and State and Federal authorities should cooperate in making studies and publishing results as to the health situation of workers in dusty places in coal mines. The introduction of rock dust into coal mines to prevent or limit explosions is a long step toward coal-mine safety and need not introduce any additional health hazard into coal mines. If the face regions of dry coal mines are kept well-watered to a distance of 40 or 50 feet from the face and rock-dusting is maintained in all other accessible parts of the mine there will be little or no health or explosion hazard. Water should be piped to all dry faces in coal mines and used on the cutting chain while undercutting, overcutting, centercutting, or shearing; faceworkers should sprinkle the face region within 40 or 50 feet of the face (ribs, roof, floor, and coal pile) at least 3 times daily, as well as sprinkle (not soak) the top of all loaded cars before they leave the face.

<u>Water</u>.- The British Coal Mines Act of 1911 (275) requires that "a drill worked by mechanical power shall not be used for drilling in ganister, hard sandstone, or other highly siliceous rock, the dust from which is liable to give rise to fibroid phthisis, unless a water jet or spray or other means equally efficient is used to prevent the escape of dust into the air." The minutes of one of the meetings of the Health Advisory Committee of the Mines Department stated that--

> In many cases no attempt is made to prevent the dust emitted from rock drills entering the air of the mine. The water sprays which are used in some cases are inefficient, as the volume of water is small and does not wet the smallest and most injurious particles of dust. The men strongly object to the efficient use of water through hollow drills on grounds which are intelligible. The results are fairly good when new drills are used, but after a short time there seems to be commonly a leakage of air into the drill, with consequent inefficiency. There are, of course, some places where water drills are used effectively, but the Committee are of opinion that another means of trapping the dust is required.

At the International Silicosis Conference in 1930 (276) it was pointed out that water is used in three different ways on the Witwatersrand: To prevent the formation of dust during the drilling of holes in blasting and the handling of broken rock; for wetting all surfaces to secure a "fly-paper" effect in retaining dust settling on those surfaces; and for spraying into the air to allay dust already formed. It was generally agreed that water applied at the site of percussion or fracture tends to minimize the formation of dust, but attention was drawn to the fact that in several operations--rock-drilling, stonecutting, grinding, etc.--sparks accompanied by dust escape even when the

surfaces concerned are actually under a film of water. The view was expressed that, since there is no particular reason why dust particles under 3 microns in size should settle on the roof and sides of working places inasmuch as they settle on the floor only after many hours, the value of these wetted surfaces as dustcatchers probably is small. It was pointed out that the dust particles with which the Conference was concerned are of the same order in size as microorganisms and that no one would expect to catch microorganisms by means of a spray. The consensus of opinion was that as sprays are of little value for removing fine dust from the air and that since a humid atmosphere and the presence of droplets had been shown experimentally to increase the risk of various infections their use should be restricted.

Some of the authorities quoted state that water does not remove all the dust from the air. According to Cummings (277) water curtains (water sprays), applied under favorable circumstances have reduced dust concentration 65 percent in contaminated air to which workers have been exposed. He states that "good ventilation, the spraying of water in air passages and upon exposed surfaces, the delaying of dust-producing blasting until the end of the working shift, and the use of respirators in hazardous atmospheres have proved effective."

The following methods for the elimination of drill dust were submitted during a "prize contest" in Germany (272): Prevention of formation of dry drill dust by adding water through the drillhammer and hollow chisel, application of water through the water head and hollow chisel, and application of water through the flush-water pipes beside the drill; removal of dust issuing from the drillhole by sprinkling the dust with water, combining dust with foam, removal of dust by dry absorption, removal of dust by suction, and deflection of the air coming from the drillhammer; removal of air floating about the face; prevention of entrance of dust into the driller by dust masks. The aim of the "prize contest" to find a method of removing the underground hazard from dust caused by drilling was not entirely attained, as a practical apparatus satisfactory under all conditions was not found.

After making a large number of tests when drilling with waterfed drills or with water sprays in operation and obtaining dust concentrations varying between 1,000 and 3,000 particles per cubic centimeter ranging from 0.5 to 10 microns in diameter, Hay (255) advises that before deciding on the use of water as a dust-preventive measure when drilling rock, careful tests should be made with a konimeter to determine whether the fine dust particles are suppressed. He brings out the further important point that a blunt drill steel, due to its pounding or pulverizing action, produces a very much greater amount of fine, dangerous dust than a sharp one; therefore, from the safety standpoint sharp drills only should be used.

Dust traps.- After working 3 years the Safety in Mines Research Board of Great Britain (255) produced an appliance which is claimed effectively to prevent the dissemination into the atmosphere of the dust produced by drilling in rock with a pneumatic percussive drill. For want of a better name this device was called a "dust trap"; it functions somewhat similar to the domestic vacuum cleaner, except that the negative pressure or suction is produced by a compressed-air-operated ejector of the venturi type.

The appliance is a telescopic standard of light steel tubing, which can be set vertically or horizontally; to this standard is fitted an adjustable right-angle bracket, which supports a short length of metal tube in which is fitted the air ejector or suction producer. At one end of this suction tube is a rubber hood with two holes, one of which connects with the suction tube and the other for the insertion of the drill steel. The filtering device is fitted at the opposite or delivery end of the suction tube. The dust-laden air is filtered through a fine-quality, closely woven flannel. The fabric itself is of very limited use as a filter for fine dust, but the layer of fine dust which becomes impacted or enmeshed in the nap of the material forms a tortuous path for the fine dust particles and restricts their passage through the filter which retains them and allows only relatively clean air to escape. The filter, in the form of a bag, is provided with an orifice at the top, forming the inlet, and an outlet at the bottom for the discharge of the trapped dust; the outlet is closed by a strong steel clip. To operate the dust trap, the telescopic standard is set up and the suction tube adjusted so that the rubber hood covers the place where the hole is to be drilled. The compressed air is then turned onto the ejector, the drill steel is inserted through the hole provided in the hood, and drilling proceeds. This appliance was officially approved for use underground after rigorous tests under practical working conditions.

Several similar dust traps have been developed and are described by Hay (255) as follows:

"Sgnonina" dust trap.- A later type of dust trap is that known as the "Sgnonina." This is a very compact, self-contained appliance. It functions in a similar manner to the one just described, but, in this instance, the apparatus is secured in position on the rock face by means of a small expanding steel mandrel to which is attached an adjustable arm which carries the dust trap proper. For fitting in position, a hole 1 inch in diameter and 2 inches deep is first drilled in the rock. The expanding mandrel is inserted into this hole and locked into position and the rubber-suction hood adjusted to the required position on the rock face. The drill steel is next inserted through the hood and drilling proceeded with, the trapped dust being retained in a filter bag similar to the one already described.

"Trewill" dust trap.- A further dust trap is that known as the "Trewill", which is the invention of a colliery mechanic. This is also a compact and efficient device. It is somewhat similar to the "Sgnonina", but has the advantage that an auxiliary hole is not required to secure the appliance in position. The suction hood is provided with a pair of strong steel jaws in the form of "duckbills" which are expanded in the collar of the hole by means of a large screw nut which is tightened with a special spanner.

"N.A." dust trap.- A still later type of trap is that known as the "N.A." invented by a colliery manager in South Wales. This device is extremely simple in design and operation. It comprises a T-piece of which one arm is in the form of a coned member. For operating this dust

trap a starter hole is first drilled to a depth of about 4 inches, and while this is being done the suction hood of the trap is held in position by hand against the rock face. The cone-shaped member is then inserted into the collar of the borehole and hammered home. The drill steel then passes through the coned member, and boring proceeds in the usual manner.

"Improved Hay" dust trap.- Some 2 years ago the author evolved a new design of dust trap which is officially termed "The Improved Hay." The general principle of this trap is exactly the same as those described but so designed that the suction hood and the filtering appliance form 2 separate and distinct units, being connected together by means of a 15-foot length of light nonkinking rubber-and-canvas hose. The suction hood is secured in position on the rock face by expanding 2 light steel tongues in the collar of the borehole against the tension of 2 spiral springs, by means of a simple cam and lever. The filtering appliance, with which is embodied the suction-producing device, comprises a filtering medium of imitation moleskin fabric in the form of a cylinder. This fabric filter is enclosed in a perforated steel container to protect it against damage. At the bottom of the container is arranged a removable receptacle for holding the trapped dust.

A more recent development of this trap is that the filter device has been redesigned with a view to reducing the size and weight of the appliance. This has been obtained by convoluting or "zigzagging" the filtering area into a much smaller space. It is considered that the considerable reduction in size of the apparatus will enhance its use in difficult and confined places underground.

"Barkston" dust trap.- Another useful trap is the "Barkston", which has been evolved by the mechanical engineer at a Yorkshire colliery. This apparatus is novel in design, as the filter appliance is arranged with two separate containers, one in the form of a cyclone dust collector for dealing with the coarse dust and the second a fabric filter which retains the fine air-borne dust carried over from the cyclone separator. The suction hood resembles others described above, but in this instance it is locked into position on the rock face by the expansion of five serrated steel fingers, similar to a boiler-tube expander.

"Collier" dust trap.- The most recent dust trap submitted for test and officially approved by the Chief Inspector of Mines is called the "Collier." This is the invention of a mechanic at a colliery in South Wales. It is somewhat similar in design to the "N.A." trap, but has one important improvement, namely that the coned member, which is hammered into the collar of the borehole for the purpose of securing the dust trap in position, forms a separate entity. This coned member is constructed of mild steel and can be made in a number of different sizes. The body of the dust trap proper, which is constructed of aluminum, is secured to the coned member by a simple bayonet joint.

Kadco dust-control system. - The results of tests made by a lead-mining company (278) of 3 Kadco dust-removal units--2 suitable for raise work and 1 for drift operations--may be of interest to those who think that even if an apparatus is satisfactory for removing the dust in underground work it may not be desirable as regards efficiency and cost of operation. The hoods of the Kadco system, through which the drill steel is drawn, control the dust at the drillhole; the dust is conveyed through rubber hose or pipe to a collar, where it is removed from the air stream, and the air is then available for recirculation in the working place. The dust is removed effectively as shown by dust counts made by the Metropolitan Life Insurance Co. A report of some of the results of the mining company's tests of this sytem of dust control follows:

The results of the drilling tests, which covered a period of about 4 months, from an efficiency or cost angle, indicate that:

1. When using Kadco, the number of minutes consumed per foot of raise was 3.899 in comparison with 5.570 when drilling dry. In other words, the drilling time, and therefore the cost, was approximately 30 percent less when the dust was removed. It is probable that the comparison would have been even more favorable if the start of the test had been postponed until the miners had become thoroughly familiar with operations of the dust-control units.

The average number of feet drilled per piece of drill steel dulled, when using Kadco, was 12.16 in comparison with 7.08 with the dry method. It is believed that the large saving in drill steel is probably due to better alinement of the drill steel and machine. There is not the same tendency when drilling with Kadco equipment for an angle to be formed at the chuck between the drill steel and the machine as when drilling wet or dry. Again, when using the Kadco equipment the location of the point of the bottom of the leg of the stoper drill is not changed while the hole is being drilled, as is often the case when drilling by the usual methods. Both of these factors cut down the amount of binding of the drill bit in the hole which prolongs the life of the gage of the bit.

2. The number of minutes per foot of drift was approximately the same on both the Kadco and wet methods, being 3.226 in comparison with 3.106. If, however, the figures for 2 of the 24 days were omitted from the Kadco average, for the reason that an extraordinary amount of time was necessitated on these 2 days due to extensive slabbing, which time was not consumed during the wet dust period, the comparison would show slightly in favor of Kadco. But for all practical purposes, the time consumed was the same for both methods. There was, however, an appreciable saving in drill steel when using Kadco, being 15.2 feet per piece of steel dulled, in comparison with 7.13 with the wet method. The 100 percent greater life of steel is undoubtedly due to the fact that the cuttings are quickly removed from the hole and are not ground up to very fine sizes, causing excessive wear of the gage of the bit as is the case in the wet method of drilling. This is clearly shown in the material taken from the dust collector, the coarser sizes being surprisingly large and forming a large percentage of the total material removed.

The advantages of using Kadco equipment in raising are:

1. The hood extension column used on the stoper type of pneumatic drill keeps the machine in correct position at all times. This enables a machineman to change steel very quickly and easily, as the machine merely slides down the column, the steel is taken out, and new steel put in, and drilling is resumed.

2. The extension column serves as a very important safety device in the event that a piece of steel breaks, as the machine only rises to a certain point, where there is an automatic cut-off of the air in the leg used to raise the machine. Also, the hood acts as a support in starting the hole and therefore greatly lessens any chance of an eye or other personal injury.

3. Another advantage is that the gases which are usually present in the face of a raise after blasting are not merely stirred up or diluted by the exhaust from the drill, but are sucked out of the raise by the suction blower on the collector.

4. If water is used for drilling in a raise, it constitutes a constant source of annoyance to the drill operator, who is more or less thoroughly soaked at the end of his shift. In addition, the water running down the raise makes the ladders and footwall slippery and results in a definite safety hazard. It was because of this risk, coupled with the chance of men contracting pneumonia or colds in the severe winter weather that is experienced at Balmat, that dry raising was used by the St. Joseph Lead Co.

5. The increased greater drilling speed using Kadco equipment indicates a considerable saving in compressed air consumed per foot drilled, up to approximately 34 percent in the case of raises.

The disadvantages are:

1. The extra weight of the equipment, being some 11 pounds for the hood and extension column, also the effort required to pull up the extra hose in the raise. If the wet drilling method was used in the raise, there would be little or no difference in time and labor required to handle the water hose, as compared to the Kadco hose.

2. The time required to empty the dust collector. In the small unit this must be done twice a shift. The fine dust is dumped under water in one of the pump sumps or water ditch, and the coarse dust is placed in an ore car and available for milling operations.

We feel, however, that from purely a standpoint of efficiency, the time lost in these two disadvantages is more than made up by the fact that the machinemen are able to stay up in a raise as long as desired, whereas when drilling dry the average drill operator did not stay for more than 2 hours before coming down to the level to get out of the dust. It has also been our practice not to keep a man constantly on raisework, even

though the dust is mainly dolomite and contains a negligible amount of silica. The resultant constant changing of men does not tend to increase efficiency or output.

In drifting operations there also seems to be some advantage in using Kadco instead of the wet method, although the results are not as outstanding as when a stoper type of drill is used:

1. There is a definite saving in drill-steel consumption.

2. There are no water lines to put in nor water hose to burst. No water needles in the drills to cut off, if a shank on the drill steel is slightly defective.

3. The lubrication of the machine is much better when drilling dry than when drilling wet, and this condition should result in lower repair cost. No comparative repair-cost figures, however, have been obtained.

4. The laying of track is done much quicker, as the bottom of the drift is not wet.

5. The wet health hazard is eliminated, and the eye and other personal risk is lessened.

6. The general mine ventilation is improved, as instead of dust-laden air moving away from the working place, the air circulation is reversed and toward the drill, by reason of the suction.

The disadvantage is the extra equipment of hoods, hoses, collectors, and the cost of same. The power consumed in running the $4\frac{1}{2}$-hp. suction-fan motor on the large collector and the $1\frac{1}{2}$-hp. motor on the small unit is a small additional operating cost.

Pyrene Foam.- The Mines Department of Great Britain has recently approved a new apparatus called the "Pyrene Foam" (279) for trapping dust. This apparatus consists of a 5-gallon foam-generating container, weighing about 40 pounds and housed in a substantial casing with 2 apertures at the top for convenience of transport and for hose connection to and from the apparatus. All fittings are protected against damage from the inevitable rough usage inseparable from mining. The foam-forming liquid, a noncorrosive vegetable product, is supplied in sealed tins in a concentrated form for diluting with water near the site of the drilling; a gallon of the diluted solution produces about 15 gallons of foam. The container is connected to the compressed-air supply through a reducing valve of the diaphragm type, which reduces the normal mine-air pressure to about 30 pounds per square inch and which forces the foam liquid through tubes inside the container especially constructed to split the liquid stream into drops; a supply of air aerates the drops into a foam with a volume 15 times that of the original liquid. It is this expansion which so materially reduces the quantity of liquid required for dust-trapping. The generator usually contains two foaming tubes, but more can be fitted to work a greater number of drills from each container. The tubes are provided with valves to regulate the flow of foam; the valves are closed when

the tubes are not in use. The important problem in the research which preceded the design of the apparatus was to produce a foam which would not break down when passed through a long length of small-diameter hose and the restricted passages through wet drills. This has been done so successfully that lengths of 120 feet of $\frac{1}{2}$-inch or $\frac{3}{4}$-inch hose may be used safely to connect the drill to the foam generator, thus reducing the time spent in moving the container and allowing it to serve more than one drill. The quantity of compressed air used is negligible; the drill usually requires only 1 gallon of foam liquid per hour as compared with about 1 gallon of water per minute for the jet of a water-fed drill. The foam is noninflammable, noncorrosive, does not impede in any way the working of the drill or cause any tendency to stick, and exerts a cooling effect on the drill. The 5-gallon container will supply enough foam to last a shift, or the foam can be delivered into a central header from which connections can be made to a number of drills. A spray nozzle can be used to apply the foam to the floor, roof, and sides of working places; to material before being broken for loading; and to material being loaded to prevent dust during working operations.

Dust respirators.- Although some form of respirator has been in use for generations to protect against dust (280) it has not proved satisfactory because it is uncomfortable to wear, and the filtering medium clogs rapidly with dust and exhaled moisture, which greatly increase resistance to air flow and impose extra and often excessive effort in breathing. Some of the discomforts may become pronounced, such as the pressure at the edges in contact with the face; the heat caused by the face cover; the warm, humid, exhaled air in contact with the face; rebreathing the trapped exhaled air; and prevention of cooling by evaporation and radiation. In cold weather the heat effects are not uncomfortable. Some respirators fit the face so poorly that much of the air is inhaled through openings between the face and respirator without removing the dust. One reason that respirators have not proved successful is that workmen will not wear them (280) for any length of time, probably because of the discomforts described above.

In 1926 the United States Bureau of Mines summarized the results of an investigation of the construction and filtering efficiency of dust respirators as follows (280):

1. The efficiencies of the industrial dust respirators in restraining tobacco smoke range from 5 to 33 percent when the air is passed at a rate of 32 liters per minute; a gas-mask canister with 2 filters of absorbent cotton showed 63 percent efficiency. The Fogler flat felt filter was most efficient, showing 97 percent.

2. The efficiencies against silica dust floated in air range from about 9 to 70 percent for the dust respirators, or about twice the efficiency against the tobacco smoke; most of the silica particles were 1 micron in diameter or 4 times the diameter of the tobacco-smoke particles.

3. As the dust most injurious to miners, stoneworkers, and many others engaged in dusty trades is about 1 micron in diameter the respirators, if work can prevent a considerable amount of dust, but not all of it, from being inhaled.

4. Although the laboratory study has shown that most dust respirators are not highly efficient in removing tobacco smoke (very difficult to arrest) from air, a filter that removes 50 percent of the tobacco smoke from air flowing at the rate of 85 liters per minute is very efficient in restraining the ordinary dusts encountered in industry and also the smokes, such as those from burning wood or other carbonaceous material, that city firemen encounter. Hence, the Bureau of Mines adopted a 50 percent efficiency against tobacco smoke by the laboratory tests as a standard requirement, besides other requirements, for the approval of respirators or gas masks to afford protection from smoke or dust.

5. As the laboratory tests of the dust respirators were severe, the low efficiencies given do not indicate the general efficiencies of these respirators under all industrial conditions. Much of the dust encountered in industry is less difficult to arrest, and the over-all efficiency of the respirators in actual service is correspondingly higher. The tests thus show that, as a rule, these respirators are of much value in removing injurious dust from inspired air.

6. The discomfort caused by respirators covering the face--the heat engendered thereby, the irritation of the skin at contact with the respirators, and the resistance to the flow of the air breathed--are the most serious disadvantages of respirators. The resistances of industrial dust respirators to air flowing at 85 liters per minute were 0.25 to 1.5 inches of water. The Fogler flat felt filter had a resistance of 2.25 inches and the gas-mask canister 3.6 inches.

7. A man wearing a gas mask can work hard only about half an hour; then the extra effort caused by the resistance to breathing compels him to stop to rest or greatly reduce his exertion. The resistance of the dust respirators, although it causes some discomfort, does not seriously interfere with a man's exertions until the filter becomes clogged with deposited dust and the resistance correspondingly increased. The filter must then be cleaned or freed of dust, or it must be replaced by a fresh one.

8. Filters of various fabrics, including cheesecloth, canton flannel, unbleached muslin, closely woven bleached muslin, filter paper, and absorbent cotton, all made for test purposes so as to expose exactly 100 square centimeters of filter area, were tested against tobacco smoke and against silica dust in air flowing at a rate of 10 liters per minute. Each material was tested in a single layer and in multiple layers. Results showed that each layer of fabric (in effect) removes about the same proportion of smoke or dust that penetrates to it before the filters become clogged or altered by deposits of an arrested material, such as silica dust. Consequently, then the efficiency of a single ply of a filter is known, the efficiency of any multiple-ply filter of that material may be calculated.

9. Silica dust clogged filters rapidly and increased the resistance to air flow, but some materials were more resistant to clogging than others. The dense filters of paper or closely woven muslin clogged most rapidly; filters of loose texture like cheesecloth or absorbent cotton clogged the least.

10. The efficiencies of the filters were increased by clogging with dust until eventually many filters gave an efficiency of 100 percent.

11. Tobacco smoke did not clog filters, and there was no increase in efficiency as the smoke was deposited.

12. A few tests were made with woolen fabrics, but they proved to be no better as filters than cotton fabrics of similar texture.

13. The efficiency of the filters decreased somewhat with an increase in the rate of air flow. Sometimes a cotton fabric with a nap showed a decrease after humid smoke had wet it and the moisture had caused the fibers of the nap to adhere together.

14. The resistance of the filters to air flow increases in proportion to the number of plies of fabrics after the first ply. The first filter layer shows a somewhat higher resistance than the additional ones.

15. The resistance of fabric filters to air flow is very nearly proportional to the rate of air flow.

16. Air filters of high efficiency can be made with a sufficient number of plies of material that has a low efficiency per single ply--cheesecloth, for example. Such filters have less resistance to air flow than equally efficient filters made of fewer plies of the higher-efficiency materials, such as closely woven muslin.

17. The thicker filters of loose-textured material clog less rapidly than equally efficient filters composed of fewer plies of tightly woven material.

18. A new type of dust respirator was designed and constructed according to the principles brought out in the tests. This respirator consists of a large filter of Canton flannel made into a cap or turban for the head. Air filters through the Canton flannel to the interior, passes through a check valve, and then is conducted through a rubber tube running over the forehead and between the eyes to the nose, which is covered with a small rubber nose cap. At an air flow of 85 liters per minute the efficiency of this respirator is 58 percent against tobacco smoke and 93 percent against silica dust.

19. The data presented and the principles outlined may aid manufacturers in improving dust respirators.

20. Although the use of respirators should be encouraged among workers in dusty industries, a respirator cannot be considered a final safeguard. In mining and in other industries effort to prevent the formation of dust and its distribution by the air, by the use of hollow drill steel and water, and by sprays on the undercutting machines should be continued.

After studying the development of a satisfactory respirator for several years the Department of Scientific and Industrial Research in collaboration with the Home Office, War Office, and Mines Department of Great Britain (255) perfected a respirator which they consider ideal from all standpoints. According to Hay (255):

> A number of these respirators have been manufactured for exhaustive trials to be carried out under actual working conditions in mines and quarries, and it is hoped that a problem of great importance is now on the point of being solved.

On August 20, 1934, the United States Bureau of Mines issued Approval Schedule 21, Procedure for Testing Filter-Type Dust, Fume, and Mist Respirators for Permissibility (281). Respirator filters are subdivided into classes according to the type of atmospheric particulate matter against which they are designed to protect. Type A is designed for protection against mechanically generated dusts resulting principally from the disintegration of a solid, such as the clouds produced in the various processes of mining, quarrying, and tunneling and the various industrial operations of grinding, crushing, and general processing of minerals. A "man-test" is required to determine whether the respirator will give adequate protection to men performing light work in an atmosphere containing an irrespirable suspension of definite concentration. Six respirators have been approved by the Bureau under this schedule.

The Colliery Guardian (282) summarizes the precautions recommended by one of the British divisional mine inspectors to prevent dust production in coal mines as follows:

> Mr. Thomas Ashley showed that the problem facing everyone connected with coal mining was to keep under control the dust made in the processes of driving in hard ground and in rippings. It was, of course, impossible to prevent the formation of dust in this kind of work. The amount of dust, however, could be reduced when drilling by not allowing the drills to be used when blunt. In hard headings in the highly inclined measures found in nearly all coal mines of the Swansea division the beds passed through were constantly changing. These varied from soft clifts to sandstones of all degrees of hardness, the latter giving rise to dusts, the breathing of which should be avoided as much as possible. During recent years a number of cases of silicosis had been certified by the Medical Board, of colliers and other classes of workmen in which there had been apparently no history of drilling or working in hard headings or in hard rocks. Preventive measures had not yet been fully worked out for these except possibly the use of respirators, but many cases of silicosis were certified by the Medical Board amongst workers in hard headings and sandstone rippings, and in these preventive measures had been developed to enable the dust to be kept under

control during drilling by means of dust-trapping devices, the use of water-fed drills and by foam injected into the shot hole. Very many of these devices were now provided for use in the mines of the division where mechanical drills were used both in hard headings and in rippings, and their advantages were, without doubt, now fully realized by both managers and workmen. However, the management's duty did not end with providing the dust traps or other means, but it was up to them, as well as the men engaged on the work, to see that proper use was made of the traps. Care needed to be taken that the position of the shot holes was so arranged that the hood of the trap could be used effectively and that the apparatus itself functioned properly. Dust traps were easily liable to become damaged. The best way to guard against this was for frequent inspections to be made of the traps by a skilled mechanic and spare traps and spare parts should be provided, so that the apparatus could be kept in proper working order. These were matters to which the inspectors of mines paid constant attention during their daily inspections underground, and by the use of the konimeter the efficiency of the preventive measures in use was determined. On an average there were no less than 30 hard headings being driven at any one time in that division. It was hardly necessary to add that the dust collected by a trap should be so treated that, when being emptied, it was not dispersed into the air, and that where the rubbish had to be conveyed away to be emptied the trams should be dusttight.

Dust also arose from the shattering effect of the explosive upon the rock following the firing of shots. This, of course, could not be trapped or its formation entirely prevented. Proportioning the charge to the work to be done, as well as care in placing shot holes, would result in less breakage of the rock and in a reduction of the dust. In this connection, however, the adoption for stemming the holes of a mixture of clay and sand would, owing to the greater efficiency of the work done by the explosive--thus allowing less explosive to be used--tend to reduce its shattering effect and so minimize the formation of fine dust. And when speaking about shot firing, there was just one other point he might mention. A shot not only produced fine dust by shattering the rock but it also raised into suspension all dust lying in the immediate vicinity. If, therefore, the area contiguous to the shot was kept as clear of dust as was practicable, less dust would be raised into suspension when the shot was fired. Since the dust formed and raised by the concussion of the shot when firing explosives could not be prevented it was necessary that means should be adopted to avoid as far as possible the exposure of the workmen to it. Shots should be fired, as far as practicable, before mealtimes and at the end of the shift, so that as long an interval of time as possible elapses before any workmen needed to return to work at the face. Under any circumstances as long a time as possible should be allowed to elapse before entering the place where the shot or shots have been fired. The better the ventilation--and it should be remembered that velocity was equally as important as quantity--the quicker would any concentration of dust be rendered harmless or removed.***.

To sum up, the problem of keeping the dust under control amounts to this:

First, take all practicable steps to limit the amount of dust produced by--

1. Reducing the amount of shot-firing to a minimum and consequently the number of shot holes to be drilled;

2. Seeing that the drills are kept sharp;

3. Maintaining the area in the neighborhood of shot-firing as clear of dust as practicable;

4. Proportioning the explosive charge to the work to be done;

5. Seeing that the shot holes are properly placed with respect to the work to be done;

6. Using slightly moist sand and clay stemming mixture for tamping.

Secondly, take all practicable steps to control the dust that is produced and so prevent it from being breathed by workmen by--

1. Shot firing only when the minimum number of persons are in the mine, preferably between shifts. This precaution would also apply when gobbing is being done in dry and dusty places;

2. Maintaining an efficient ventilation during drilling and also while filling the rubbish into trams;

3. If necessary, fixing a definite interval between the firing of a shot and the return of the workmen;

4. Collecting the dust made when drilling, by dust traps, water-fed drills, or by using foam.

Dust filters.- In a paper on Mine-Air Filtration Cowles and Flugge-de Smidt (283) describe methods tried in South African mines for removing dust produced in ore bins and at tippler stations. Dust so produced is added to the air currents if the bins or ore passes tend to upcast, as they usually do. Although sprays and doors are of some assistance the only effective means of preventing this dust from rising is to induce constant downcast currents of air through the tipping points. In one instance the dust-laden air, drawn from below the tippler level, was led direct to the upcast shaft; in another a similar installation discharged into a large worked-out area, where much of the dust settled; and at East Geduld, where neither of these systems was possible, flannel-bag filtration was successful. The paper by Cowles and Flugge-de Smidt deals mainly with air-filtration experiments and filter plants at ore passes but also includes descriptions of a filter-bag installation used in a development section to permit double-shift blasting and of the filter plant attached to the surface crusher station.

Flannel was found to be the best filtering medium for the bags. Konimeter counts after filtration range from 60 to 100 particles per cubic centimeter, and the weight of dust caught per day is approximately 18 pounds. The authors (283) describe the filter plant as follows:

> The main tippler station at East Geduld is on the 5th level. Some 1,500 tons are tipped into both the north and south ore passes daily, and in addition about 1,000 tons, tipped on the 4th level, enters the south ore pass just below the 5th level. 400 tons are tipped in the waste pass. The two main ore passes join above the underground sorting station. All the tipplers had a tendency to upcast, causing dusty air to pollute the main fresh-air intakes. The dilution beyond the tipplers was such that counts of from 100 to 150 particles per cubic centimeter were seldom exceeded. Bad conditions prevailed when rock was tipped into empty bins or when the 4th level box was run into the south ore pass. At such times surges of upcast air gave pyramids of dust on konimeter spots sampled at the tipplers.
>
> It was decided to cause all the tipplers to downcast by exhausting sufficient air from each of them and to filter this air. A vertical winze, 9 feet diameter was sunk in a central position to a depth of 24 feet and crosscuts were driven from the bottom of the winze to each of the three passes. A filter chamber was cut from the winze, below the station level, and lined with concrete in order to retain the strength of the station pillar. Filtered air divided equally into the intakes to the north and south sections of the mine. The completed size of the chamber is 30 feet by 11 feet by 8 feet high. The fan selected was a 30-inch Aerex capable of circulating 18,000 c.f.m. against 2½-inch W.G. It has four slender propeller blades and no guidevanes, so practically no dust collects in the fan. The motor is enclosed within the fairing in the fan, which itself is made to draw fresh air from outside through the motor, in order to prevent clogging by dust. The fan exhausts air from the vertical winze through 36-inch piping and from the bottom of the 4th level box through a 16-inch pipe. It delivers into a large header with nine 18-inch-diameter outlets to each of which a flannel bag, 18-inch diameter by 20 feet long, is attached. The bags are supported by means of felt-lined metal rings which are suspended from the roof. The filter fabric area is approximately 1,000 square feet, giving a linear speed through the cloth of about 20 f.p.m.
>
> All three tiplers became strongly downcast when the plant was started up, and it could run for a week before the resistance of the bags rose to 3-inch W.G. The bags are now changed twice weekly, and the resistance does not rise above 2 inches.
>
> The efficiency of the dust chamber has far exceeded the writers' expectations. Except during the first day's run with new bags it has been practically impossible to obtain a konimeter spot and even a Zeiss konimeter, taking 25-cc samples, has shown no spot on an untreated slide. The Greenburg-Smith impinger apparatus was used to obtain comparative results. The air to be sampled by this instrument is made to impinge through a nozzle onto a flat plate under water. 200 cc of distilled water in a glass bottle are used for an ordinary sample.

We believe that the filtering accomplished in this plant is of a high order, firstly, because of the inability to obtain konimeter spots and, secondly, because of the optical properties shown by the Greenburg-Smith impinger samples of filtered air, and we claim that the filtration of over 99 percent, obtained in the last 2 tests shown in the table, represents the normal efficiency of the plant. These results are due largely, in our opinion, to the dilution that lessens the concentration of dust passing into the bags. ***. We were also concerned with the discrepancy between the size frequency of the particles in a Greenburg-Smith impinger sample of unfiltered air and that of the dust caught in the bags. The former revealed nothing over 6 microns while particles up to 50 microns were found in the latter. Our feeling that something was wrong with the sampling of unfiltered air was supported by a comparison of the actual dust caught with the theoretical amount called for as revealed by the average of five 24-hour Greenburg-Smith tests. Only 14 pounds of dust per week was called for, whereas 80 pounds of dust was caught. It appeared possible that the unfiltered air was not representative, either as regards dust contents or size of particles, due to sampling through a nozzle facing downstream. This was tested out by turning the nozzle toward the fan with the results shown in the last 2 tests which, incidentally after averaging, called for a dust catch of 77 pounds per week and showed particles up to 30 microns in size.

During a discussion of the paper by Cowles and Flugge-de Smidt (283) the president of the association called attention to electrical precipitation, which is beyond the experimental stage, many plants now very successfully removing dust, gases, and noxious fumes in various industrial processes. Jeppe (283) stated that--

> The tenacity with which the grim battle against silicosis has been fought and is being fought is one of the epics of Rand mining. It may be that victory will never be complete: at least, however, success has been gained on many fronts and the struggle never ceases.

He also made the following comment on the investigations reported by Cowles and Flugge-de Smidt:

> The success with which these investigations have met is very clearly shown in this paper now before us: Dustcatching efficiencies of 98 percent and 99 percent have been obtained on the plants installed at the East Geduld mine, and it has been found possible even to eliminate to a negligible point the dust produced by blasting, so that double-shift blasting has now been made practicable. This must be recognized, I think, as a wonderful achievement, far in advance of what could have been anticipated a few years ago.
>
> This paper also, I think, has to a considerable extent crystallized our knowledge of the main essentials for efficient dust-trapping:
>
> 1. The downcasting of the tippler or bin by the installation of a fan.

2. The collection of this dust by passing the air through appropriate filtering material of such an area that the linear velocity is about 20 f. p. m., and

3. The exhausting of this treated air into adequate currents of air for dilution.

All these factors are essentials.***.

There is one point in connection with these dustcatching plants with which the authors have not dealt in detail, and which merits, I think, our close attention; and that is, Do these filters catch the finest dust?***.

Professor Kettle is of the opinion that it is the finest dust which causes silicosis--dust so small that it can be absorbed and at least partially dissolved by the lung tissues and which then acts, in some unknown way, but probably chemically, as an irritant, causing silicosis. He states that his best results--best, that is, from the scientific point of view of causing silicosis--are obtained with flint dust which is 70 percent less than 0.8 micron in size--that is, of a size smaller than can be seen with an ordinary microscope.

With this viewpoint Mr. Adler has suggested that filter plants should be designed for two stages--the first to catch the coarse dust and the second to catch the fine dust. His theory that the flagellae or cilia of flannel catch the fine dust, when the velocity of the impinging particles and the velocity of the waving cilium are equal, is of more than academic interest; if it be accepted then the best materials to use as filters, ceteris paribus, are obviously those with the most efficient supply of such flagellae; and this indeed is, I think, borne out in practice.

It may be mentioned, however, that the possible nonelimination of this finest dust has been allowed for, to some extent at least, in these filter plants at the East Geduld, by the subsequent dilution of the treated air: for it is known fairly definitely that efficient dilution nullifies the harmful effects of dust of any size.

Dust Control in Industries Other Than Mining

Ballantyne (108) directs attention to the fact that the ameliorative measures adopted almost universally in dealing with silicosis have not called for the complete suppression of dust--the unattainable ideal--but have followed the lines of preventing the inhalation of dust as far as practicable, keeping the worker under medical observation and control and paying compensation if the worker is attacked by the disease. He states that the processes carried on in the industries vary so widely and call for such different treatment that each must be studied alone. Quarrying rock, grinding cutlery, and making pottery have little in common, except that they give rise to siliceous dust; therefore, the means adopted for allaying, trapping, or withdrawing the dust obviously cannot be the same in all instances. There is a broad scope for ingenuity in the design of plant suited to the needs of each.

Many of the methods of value in control of dust in mines--as the use of water, ventilation, and dust collection--are largely applicable to other industries.

Smith (284) states that the prevention of silicosis may be aided by such combinations of the following measures as are feasible: Substitution of nonsilicosis-producing material, such as a metal abrasive for sand, nonsiliceous parting compounds for molds in foundries, and clay instead of flint in bedding potteryware for baking; enclosure and segregation of dusty processes, as the use of sand-blasting cabinets; local exhaust ventilation for the removal of dust at point of origin; suppression of dust by water--sprays and steam help in conjunction with other methods but should not be overestimated; general artificial ventilation; plant cleanliness, which is as important as upkeep of protective equipment; direct protection of the worker, although masks and helmets have serious operating limitations; alternation of work, which should be more frequently applied; medical supervision; education--workers need to be impressed with the risks, instructed in the use of equipment, and encouraged to submit to physical examination; and dust-counting to check the efficiency of the measures should be a part of preventive programs.

Dust Control in Abrasives and Grinding Industries

An investigation made in 1919 by Winslow and Greenburg (285) revealed that establishments devoted to the manufacture of abrasive materials may present conditions as regards aerial dust content scarcely equaled in any other industry. In the carborundum-grinding department of the factory it was found that virtually no precautions had been taken; in the aloxite department the grinding room was provided with enclosed machinery, and the lathes were equipped with an exhaust system which the management believed was adequate. However, a careful examination of the system showed that it was gravely defective in several respects. Its principal shortcomings were cited by the authors as typical of conditions frequently noted in the inspection of exhaust systems designed or operated by those unfamiliar with the principles of efficient dust removal.

> The exhaust ducts were so small that their high frictional resistance greatly increased the cost of operation and made it very difficult to maintain an adequate suction pressure. Furthermore, such small pipes tend to clog with lint and dust, and dealing with the latter tendency was made doubly difficult because an insufficient number of clean-out handholes was provided.
>
> The system as installed had been allowed to deteriorate seriously for lack of careful maintenance. Many ducts were noted with broken joints. The dust separators in some cases were in very bad condition, large holes being plugged only with rags and waste.
>
> Partly as a result of conditions noted above or, to look at it in another way, due to the lack of sufficient fan capacity to overcome these limitations, the suction pressure in the exhaust system was far too low to be effective. With the exception of the ducts serving certain shaving hoods, this pressure never exceeded that of a 1-inch water gage.

Finally, the hoods for removing the dust from the immediate vicinity of the machines were defective in design. Such hoods should be so arranged as to apply as large a fraction as possible of the suction velocity in the exhaust pipes to the dust at its point of formation, and the suction should preferably be applied from such a direction as to take advantage of the tangential momentum imparted to the dust as it leaves the wheel. Instead, we found most of the machines entirely lacking hoods, the exhaust duct merely terminating in a funnel-shaped opening below the center of the machine spindle so far away that the velocity of the exhaust was scarcely perceptible at the face of the wheel.

The disease-prevention value of substituting a less dangerous for a more dangerous material in certain dusty industries is indicated by the experience in an ax-grinding plant in Germany. The director of the research department (286) was asked to determine the reason for the sudden increase during the preceding 6 years in the number of deaths due to silicosis and silicotuberculosis among the workmen in the plant. The most striking changes of operation during this period were the elimination of the midday dinner hour and the substitution of Pfalz for Eifel grindstones. Investigation revealed that the amount of dust resulting from grinding with Pfalz stone was considerably greater than with the Eifel stone. The latter did not produce weighable dust during the same period that the Pfalz stone produced 13.3 to 37.7 mg in 1 m^3 of air. The dust count for the Pfalz stone was correspondingly higher than that for the Eifel. Analysis showed that the Pfalz stone was 33 percent higher in silica but lower in aluminum oxide than the Eifel stone. Pfalz dust showed 0.9151 gram of crystalline silica per gram of dust, while the Eifel dust showed 0.623 gram of the same substance. The Eifel is considered by far the less dangerous stone especially since it contains a larger amount of bond in the form of aluminum oxide, which tends to make the dangerous silica particles far less dangerous in the dust. According to Clark (286), this paper is of interest because it supports the belief that the higher the silica content the more dangerous the dust, and the higher the dust count the greater the health hazard (provided the dust is dangerous). Aluminum oxide is not a factor in the production of silicosis; this fact is of special interest because most artificial grinding wheels are made of aluminum oxide crystals held by a vitrified bond. The results of the investigation confirm the value of industrial-hygiene plant control and continuous successive examinations of employees to determine whether a health hazard is developing.

In 1933 Bloomfield and Greenburg (287) reported the results of a study of air-pressure abrasive-blasting operations in the United States made by the United States Public Health Service during 1929-31 in cooperation with the National Safety Council. Preliminary surveys were made of 355 pieces of abrasive-blasting equipment operated by 536 workers in 44 plants in 8 States. In 64 percent of the instances the abrasive used was sand; in 34 percent, metal (steel grit and shot); and in 2 percent, a mixture of sand and metal. The surveys included inspection and classification of equipment as to kind, quality, maintenance, general housekeeping, age of installation, and type and maintenance of respiratory protective devices. As a result of these preliminary surveys, detailed studies were undertaken in 28 shops in Connecticut, Michigan, Wisconsin, and Illinois. The shops contained 194 pieces of

abrasive-blasting equipment; 27 percent, rooms; 33 percent, barrels; 7 percent, tables; 10 percent, cabinets; and 23 percent, others. Virtually all the dust in the air of the workrooms was less than 3 microns in size, the model size was between 1 and 1.5 microns, and only 1 percent was less than 0.5 micron. When sand alone was used as the abrasive the quartz content of the dust in the air ranged from 42 to 93 percent, depending upon the cleanliness of the castings being blasted; when sand and metal mixtures were employed the quartz content of the atmospheric dust averaged 44 percent; and when metal abrasive was used it averaged 3 percent. With sand abrasive the average dust concentration to which the workers were exposed for the different types of blasting equipment, in million particles per cubic foot of air, was: Rooms (exposure under helmets with nonpositive pressure), 241; rooms (exposure under helmets with positive pressure), 4.7; barrels, 29; tables, 25, cabinets, 3; automatics, 24. When metal abrasive was used the concentrations, in million particles per cubic foot of air, were: Rooms (exposure under helmets with positive pressure), 1.9; barrels, 15; tables, 17. Even in a well-designed and properly ventilated room with metal abrasive on clean castings the average dust concentration in the workroom air was 49 million particles per cubic foot, indicating the necessity of special protection for the worker. As a rule, this protection consisted of helmets, masks, and hoods. With positive-pressure helmets the average dust concentration in the air to which the worker was exposed was 5.5 million particles per cubic foot (maximum, 25), whereas with nonpositive-pressure helmets the average was 581 (maximum, 1,912).

A study of the amount of dust in the air supplied to the positive-pressure devices (287) disclosed an average of 1.8 million particles per cubic foot and a maximum of 7.9 million. Tests on the amount of air supplied showed that most of the devices received 4 to 10 cubic feet of air per minute. Special experimental studies indicated that the provision of a positive supply of 6 cubic feet of dust-free air per minute will protect the worker under the operating conditions now in practice in abrasive-blasting rooms (no blasting-room dust filtered into the helmet when this amount of air was provided). When abrasive-blasting was in progress in rooms there was an average of 20 million particles per cubic foot of air and a maximum of 180 in the general workroom air, whereas when no blasting was in progress these values were 3.5 and 9.1, respectively. It was observed that poorly designed and maintained equipment was responsible for much of the pollution of the workroom atmosphere. For example, provision of exhaust housing about barrels reduced the average concentration of dust in the workroom from 38 to 2.2 million particles of sand and from 25 to 6.2 million particles of metal. Studies of equipment regarded by manufacturers as ideal and properly maintained showed an average dust concentration of 1.7 (barrels), 0.9 (tables), and 1.9 (cabinets) million particles per cubic foot of air. The maximum in no case exceeded 4.5 million particles per cubic foot. Bloomfield and Greenburg (287) concluded that dissemination of dangerous amounts of dust into the air could be prevented by equipment properly designed and maintained. However, this statement did not apply to rooms where respiratory protective devices would still be needed.

Assuming that employers in hazardous trades are not only willing but very anxious to protect their workmen, Willson (265) considers the steps by which they can approach this end:

These steps, undoubtedly, involve not only the expenditure of sufficient money to procure the best possible modern protective equipment (ventilators. exhaust systems, dust collectors, respirators, and the like), but also a readiness to face the expense of subjecting their workmen to thorough physical examination when employment starts and to reexamination at intervals not exceeding 6 months during the entire course of employment.

Employers should see that workmen are not exposed to the danger of tubercular infection from one another, that every facility in the way of dressing rooms, lunch rooms, and wash rooms is provided, and that every piece of protective equipment is kept in perfect working order.

Good housekeeping is, after all, one of the major considerations in the protection of workmen where there is dust of a hazardous nature. Dust-exhausting systems are of no use unless they are so applied to the work as to really carry off a large part of the dust and deposit it in receptacles where it cannot again work harm. Preferably the suction should draw the dust downward, away from the face of the operator. Many dust-collecting systems suffer from operation. In one plant visited last year the author noticed that the flue pipe between the inlet and the exhaust fan had opened at a joint so that air drawn in at the working entrance--if any was drawn in--tended to be thrown out again into the room at an elevated point, thus greatly augmenting the original hazard.

Then, too, sand-blast cabinets should be kept in perfect working order so that they do not send out into the atmosphere jets of dust from bad joints, leaky doors, or tattered curtains. Frequently the hoods over open sand-blasting cabinets are badly designed for protection against fine dust. Helmets used by sand-blast operators must be of modern design, supplying to the workman ample pure air; otherwise they are worse than useless.***.

Naturally, the first type of mechanical protection to come to our minds is that provided by systems of dust exhaustion. These are very effective when the inlets are applied close to the source of dust production, but their utility is less evident when they are considered in connection with suspended dust in large workrooms; in such open spaces ample ceiling ventilation and air cleaners are more helpful.. There seems to be difficult in the way of the removal of fine-dust deposits in room spaces by any mechanical or electrical means other than the direct application of good vacuum-cleaning apparatus.

Protection of workmen by means of respirators is also indicated where-ever the room air cannot be kept moderately free from dust, and, of course, doubly indicated in operations that are unusually dusty. In all kinds of sand-blasting, workmen should be individually protected, without fail. When possible, the form of respirator which provides for the workman an ample supply of pure, fresh air under direct pressure is certainly the best, provided every precaution is taken to see that the air is free from oily vapor and dust. There are, however, some occupations in and around plants where direct-pressure respirators cannot be employed without greatly impeding the necessary activity of workmen, and in such places much care should be taken

in the selection of dry-filter respirators to see that these are not only efficient and easy to maintain in good working condition, but also are as comfortable as possible. The use of wet-sponge respirators is a doubtful practice, owing to possible variations in the quality and size of sponge, degree of wetness, cleanliness, and other factors.

More often than not employers urge that their workmen are not willing to wear respirators or that they wear them only occasionally. It must be evident to anyone that if this neglect of personal protection is actually practiced the situation from a protective standpoint could not possibly be much worse. Part-time protection can hardly be considered as protection at all--rather it is only a form of self-deception. If workmen will not wear respirators because of alleged discomfort, an effort must be made to provide them with devices that really can be worn during full-time employment; but full cooperation will probably not be attained without acquainting the worker with the danger to which he will be exposed if totally or partially unprotected.

Dust-Collecting Devices

Drinker (288) states that such devices as respirators and positive-pressure helmets should be considered only as emergency equipment if dustiness can be controlled by dust-collecting equipment and exhaust fans but that there are many processes in which respirators and other protective devices have an important place and probably will for many years to come.

The March 16, 1934, issue of Iron and Coal Trades Review (289) describes a dust collector for grinding machines:

> The suppression and removal of dust incidental to dry grinding operations is, of course, a legal obligation. Settling chambers, coke and water tanks are primitive forms of interception which are bulky, difficult to clean, and none too efficient when dealing with fine dust. Fabric dust collectors, though most efficient, can only be economically applied to large installations, where a number of grinders are working simultaneously.
>
> The Visco dust collector has been specially designed for unit application. It is made in two types, that is, for light duties such as surface grinders, etc., and for heavy duties such as fettling, etc. Both consist essentially of a specially designed hood, an efficient exhauster, and the dust collector proper. The exhausters, which are designed for dealing with dust, may be either belt or direct motor-driven. In the standard designs they are mounted on the dust-collector casing, the suction inlet is connected to the grinder hood by galvanized ducting or flexible hose, the discharge being direct into the collector.
>
> The collector for light duties has a sheet-metal casing with baffle and deflecting plates acting as a settling chamber for the bulk of the heavy dust. The remaining light dust passes through a filter cell, operating on the well-known Visco principle of oilfilm-covered surfaces for the retention of the dust. The cleaned air is returned direct to the workshop.

For heavy duties, such as fettling, the cells would clog too quickly and a more efficient primary separator of the cyclonic type has been embodied, into which the dust-laden air is discharged at high velocity and is propelled by centrifugal force through the vanes into the collecting chamber forming the base. The efficiency of this primary separator is such that only a very small quantity of dust is carried by the air stream to be caught by the Visco cell.

From time to time the accumulated dust is removed from the collector casing, and the cell is cleaned by jarring it on the floor, which serves to remove the major portion of the accumulation of dust. The rest is washed out with hot soda solution; the cell is then dried and recoated. Whilst, as already stated, the collector was primary designed for unit application, there is, of course, no reason why two or more grinders should not be coupled to one suitable collector unit. Quite apart from a legal obligation, the beneficial effect of these dust collectors on factory conditions makes their installation well worth while.

According to Hatch (260), dust particles, generated by whatever means, require energy for their dispersion by means of air currents created by the operation of the dusty process. The counter-forces set up by the exhaust hood or other control device to prevent the dispersion of dust must be directed therefore (1) against the energy of the dust particles and (2) against that energy which produces air currents around the machine. Since these forces of dispersion are different in form proper design of equipment depends upon an understanding of their relative magnitude and the manner in which they act. The first lends itself to approximate mathematical analysis; the second depends upon the action of the dust-producing machine, and its evaluation requires careful analysis of the details of operation of the process. Hatch (260) states that, although his equations are not absolutely correct and do not hold over the entire range indicated, nevertheless they are correct in their relative orders of magnitude and demonstrate the important principle that whereas large particles may be dispersed by dynamic projection through still air microscopic particles, because of their relatively enormous surface area per unit volume, do not travel any appreciable distance by virtue of their own kinetic energy. He illustrates this principle by the action of a grinding wheel. Large particles are thrown off by centrifugal force and may be projected a considerable distance through still air, as the path of incandescent particles indicates. This force, however, is not great enough to disperse the fine particles, some of which may be carried in the air stream created by the "drag" of the large particles and thus escape with them; but most of them are dispersed by air currents induced by the fan action of the rotating wheel. Therefore an exhaust hood placed in the path of the incandescent large particles may not be adequate, as this neglects the fine (and nonluminous) dust that is dispersed with escaping air currents around the periphery of the wheel.

Exhaust hoods.- The concept of the dual function of an exhaust hood, arising out of Hatch's (260) analysis, suggests to him that for successful dust control three steps must be taken:

1. The kinetic energy of the large particles must be destroyed. These particles are not important hygienically, but they must be captured in order to prevent the escape of fine particles in the air stream created by their "drag." Their energy can be destroyed by means of barriers against which the particles impinge and lose their velocity, and the air currents induced by their motion can be dissipated by setting up countercurrents in the zone of dust generation by means of airflow into the exhaust hood.

2. Air currents created by virtue of the operation of the dusty processes must be eliminated through changes in the machine or more generally by the application of suitable baffles and housing to prevent their formation.

3. Air currents around the machine that cannot be eliminated must be changed in direction and made to flow into the exhaust system. This is accomplished by means of the potential gradient established between the suction opening and the surrounding air. Through hood design, the gradient must be maintained at the proper slope from the area of dust production and at a minimum slope from the so-called ineffective areas in which no dust is produced. A knowledge of the aerodynamic characteristics of suction openings is therefore essential to proper design.

Fundamental specifications for exhaust hoods cannot be established simply from a consideration of these factors. Experimental investigation must remain the most valuable aid to design. Nevertheless, the creation of a real science of dust control, which has been made necessary by the widespread industrial dust hazard, must be based upon physical laws. Empirical methods cannot be depended upon to relieve the heavy financial load that the dust hazard has placed upon industry.

In 1932 Dallavalle and Hatch (290) stated that the fundamental purpose of an exhaust hood is to create air velocity at the point of dust generation, not to develop "suction", which is a failure as a measure of hood efficiency.

Dust traps.- The fact that a dust-producing operation is conducted outdoors does not indicate necessarily that the air in its immediate vicinity is free from harmful contamination. Rock-drilling is not confined to underground work but is employed extensively in open excavation for building foundations, subway cuts, and trenchwork, in quarries, and in many other places where surface rock is removed. As these operations are carried on in the open where wind currents serve to disperse the dust a silicosis hazard generally has not been associated with them in the past. However, Smith (133) demonstrated that a real hazard exists, and a silicosis committee, appointed to advise the New York Department of Labor on the preparation of a code to cover this hazard, recommended the following (291):

1. Rock drilling, blasting, and excavating in New York City constitute a serious hazard to the health of the workers, owing to the constant exposure to silica dust, resulting in silicosis and tuberculosis. Remedial measures are urgently needed.

2. Efforts must be made immediately to improve markedly, by controlling the dust concentration, the conditions under which the men employed in these occupations are compelled to work.

3. Compensation should be granted by law for disability due to silicosis.

A second committee was appointed to investigate dust-control equipment for use with rock drills and to formulate engineering specifications for its design and operation. The attention of the committee was directed toward the Kelly dust trap, which had already been used in conjunction with an exhaust system. An investigation was made of the efficiency of this device for use with pneumatic rock drills of the jackhammer type. Dust concentrations at the breathing zone of the drill runner were correlated with the rate of air flow through the hood. The rate of flow necessary to reduce the dustiness below the standard of permissible dustiness--5 million particles per cubic foot of air--was found to be 60 c. f. m. A number of check tests with the trap operating at this rate showed that the rate was satisfactory and that it could be used as the basis for design of dust-control equipment for rock drills of the jackhammer type.

The Kelly trap is a metal chamber designed to enclose the drill steel at the rock surface (291). No attempt is made to effect a mechanical seal with the rock or between the trap and the drill steel. The dust is captured by an air stream as it wells out of the hole and is carried into an exhaust system to which the trap is connected. Escape of dust particles through the openings between the uneven rock surface and the trap or around the drill steel is prevented by the air seal produced by the inflowing air. Unlike many previous attempts to capture the dust generated by rock drills, this device is not actuated by an ejector operated by the exhaust air from the drill. It is connected to an independent central exhaust system which may be designed to accomodate any number of drills and which is provided with a highly efficient dust-collecting plant. The trap, shaped very much like an inverted tin dipper, is split to facilitate insertion and removal of the drill steel, and the two halves are connected by a spring hinge. A simple catch keeps the trap closed during operation. The hole through which the drill steel passes is 1-5/8 inches in diameter, and the diameter of the steel is 1-1/4 inches or less; free rotation is thus permitted. The trap is ruggedly constructed to withstand the rough usage to which it is subjected in the field. Air is drawn through the trap into the exhaust system by the side connection, which is 2 inches in diameter. To provide flexibility of operation the connection to the main suction system is made by flexible hose, which may be in various lengths to accomodate different types of work. Since the trap encloses completely the point of dust generation Hatch, Kelley, and Fehnel (291) state that efficient operation will be attained when the air velocity through the openings between the rock and the trap and around the drill steel is great enough to prevent the escape of dust particles and when enough air motion is set up within the trap to carry away the large amount of material as it emerges from the hole. Therefore, the total air flow through the trap required to produce this condition must be determined experimentally, the criterion being the dust concentration at the breathing zone of the drill runner.

In 1933 the investigation of the efficiency of the Kelley device was extended to include its application to underground conditions. The tests were conducted in an experimental mine. They indicate (292) that for horizontal and down drilling a rate of air flow of 200 c. f. m. through the hood is sufficient to reduce the dust concentration at the breathing zone to below 10 million particles per cubic foot of air. The average count obtained with the drifter in the stoping position was 11.6 million, but with certain modifications in the hood it has been applied to the stopehammer with satisfactory results. Dust counts obtained with wet drilling, using both the South African and the American type wet drills, were higher than those given by the blower-type drill. The need for efficient and compact dust-disposal plants for underground work is pointed out.

At the meeting of the American Institute of Mining and Metallurgical Engineers in February 1934 Brackett (293) described a recent special vacuum producer and separator equipment. The outfit consists of a metal cap placed against the face of the rock, through which the drill steel can be inserted easily, and a vacuum producer, to which it is connected through a primary and secondary separator by means of flexible hose. Hoods have been adapted for vertical, horizontal, and stope drilling and are so arranged and mounted as to become immediately effective when collaring the hole and remain in place continuously. The drill steel can thus be changed without inconvenience or delay to the drill operator. No attempt has been made to maintain a tight seal between the hood and the face of the rock, as a large enough volume of air is maintained through the hood to draw a steady stream of dust-laden air, wet or dry, from the drillhole. The hood is held in position for horizontal drilling by an adjustable arm extending from the drill column; provision is also made for holding the hood in stope drilling. For vertical drilling in quarry or surface work the weight of the hood and the fit around the drill steel is sufficient to keep it in place. The hood and the first or primary separator are connected by flexible rubber hose, usually about 25 feet long, small enough in diameter to be handled easily and large enough to keep and maintain a sufficient vacuum when passing the required volume of air. The primary separator can be arranged for either wet or dry drilling, and 95 to 98 percent of the dust or sludge is collected at this point. This container is large enough to hold approximately half a day's drilling of 1 operator, and 1 is supplied for each drill. Extra primary separators should be available to allow replacements and removal of the full units to the surface or other convenient point for emptying. This practice prevents the possibility of stirring up any dust in the confined area and also allows convenient deposition of the dust, which incidentally has a market value. The primary separator should be located as close to the drilling as possible, usually about 25 feet. From the primary separator a second length of hose connects the secondary separator and vacuum producers; this can be either a stationary or portable unit, depending upon local conditions. For stationary installation these connections would be made to inlet valves located at convenient intervals on a pipe line extending throughout the entire project as in a central vacuum-cleaning system used in hotels, office buildings, etc. The vacuum producer and secondary or bag-type separator are mounted in some convenient place and exhaust into the general air either underground or on the surface. This type of installation has the advantage that it is not limited as to weight and it

would be practicable to take care of as many as 50 drillers operating at one time. On the other hand, a portable unit must be small and light enough to be handled easily yet the filters must have enough bag area to remove the very fine particles of dust--less than 10 microns in size. Brackett (293) describes a portable vacuum producer which incorporates all these desirable features, including lightness, convenient carrying handles, and with powerful enough suction to remove all dust particles and maintain low dust counts. It consists of the bag filter or secondary separator, where the fine particles are collected, and the centrifugal-type vacuum machine mounted as an integral unit. This entire machine weighs less than 200 pounds and can be furnished with an electric or air motor or can be driven by a gasoline engine. The filters or bags are arranged so the dust collected is deposited in an easily removable pan at the bottom of the separators.

Brackett (293) stated that a unit arranged for handling two drills was tried out in a mine with very satisfactory results. The entire equipment, consisting of hoods, hose, primary separators, and secondary machine, was of such sizethat it could be lowered at one time in the lift and moved to the working zone on a regular mine timber car. Power for the electric motor was supplied by the trolley circuit, although air from the drill air line could have been used if an air motor had been available. Dust counts were taken of the general mine air and also at the driller's breathing zone while drilling was in progress, with and without the dust collectors running and with and without auxiliary ventilation. Holes were drilled with standard stope drills, wet and dry, to determine what might be expected from this type of protective equipment. The dust counts varied considerably; 2 to 14 times the original dust content was added when drilling without the hood. With the hood from $\frac{1}{2}$ to 2 times the original dust content was added, and in all cases the final result was well within the usual accepted safe limits.

From dust counts taken under a wide variety of conditions Brackett (293) concluded that for underground work where the required dust count is not particularly low some form of water-tube drills or dry drills could be used with the dust collector. Where a dust count of below 5 million is desired in underground or confined areas water-tube drills will be required with the dust collectors. For surface work in quarrying and excavating hollow piston or air-tube drills with the dust collectors will maintain satisfactory working conditions.

Dust filters.- According to Ollett (294), every machine or industrial process that produces dust is a potential source of danger to the health of the employees, whether the dust is of wood, metal, or of a siliceous nature. Virtually all such machines can be fitted with hoods or hoppers into which the dust is drawn by an exhaust fan so that the bulk of the dust is caught at its source. He states that the very finest dust particles, which are the most harmful in their effect on the lungs, are also the most difficult to collect both at the point of production and in the dust separator. Coarse dusts can be separated readily from the exhaust air in the usual forms of settling chambers or cyclones in which the dust is thrown out by gravity or centrifugal force. Such devices, however, are ineffective for the elimination of fine impalpable dust particles; for the latter the automatic bag filter

gives highly satisfactory results. This filter, as described by Ollett (294), consists of separate compartments, each having a group of special cloth filter bags suspended from automatic shaking gear at the top and fitting over spigots connected to hoppers at the bottom. The dust-laden air is drawn by the main suction fan into the bottom of the hoppers, where the heavy dust is deposited; the air then passes into the inside of the filter tubes from below. The fine dust is deposited on the inner surfaces of the tubes, and the clean air passes through automatic dampers into a common header, which is connected to the suction main. At regular intervals each compartment is isolated in turn from the suction fan and receives a supply of scavenging air from a separate fan, the filter bags at the same time being shaken by the automatic gear. The scavenging air passes through the bags from the outside to the inside, and this reversed air current, assisted by the shaking of the bags, dislodges the accumulated dust and deposits it in the hopper below. The hopper is fitted with a spiral conveyor, which discharges the dust through a rotary star valve into suitable receptacles. Ollett (294) states that this type of plant is especially applicable for the recovery of fine dusts of a harmful or valuable nature, as zinc oxide, soap powder, chemicals, ores, milk powder, flour, cement, etc., too fine to be collected in gravity or cyclonic separators. With this type of separator the warm exhaust air can be returned to the building from which it has been extracted, if desired for reasons of economy in heating costs, as the filtered air is virtually free of even the finest dust. Beyer (295), however, states that it is a common and dangerous practice in many dust-removal systems to return the filtered air to the plant to conserve the heat that would be lost if it were discharged outside the building. He found in five such systems, where dust counts had been made, that the air unquestionably was not fit for return except in one case. In one instance over 47 million dust particles per cubic foot were found in the air being recirculated--many times that considered a safe limit.

Ollett (294) mentions that the problem of dust collection at the rock face in underground works is more difficult than at machines on the surface, and very little progress seems to have been made so far in this direction. Portable vacuum exhausters of the turbine type with self-contained dust-storage bins were tried some years ago in a phosphate mine in the North of England. Flexible suction hose pipes were run from the machine to the rock face; a special form of hood through which the drill was inserted made a loose fit on the rock face. The exhaust from the compressed-air drill steel forced the dust from the end of the hole back into the hood, whence it was carried by the suction into the dust separator. He believes that this type of portable exhauster offers great possibilities in dealing with the dust produced at the rock face. Another and possibly the principal source of trouble experienced in the confined spaces of underground workings is the fine impalpable dust which remains floating in the atmosphere for a considerable period after the shots are fired. Ollett (294) calls attention to the fact that experience in the United States has shown that general ventilation of the headings is the most satisfactory solution known. The dust-laden air is exhausted and passed through large stationary filters, which must be of the automatic self-cleaning bag type already described; the clean air is returned to the headings. Ollett's statement would indicate that this method is used generally in the mines of the United States, but it is used in only one or two mines experimentally.

Brackett (293) has summarized the various methods employed in the attempt to maintain safe dust concentration in the air as follows:

1. Prevent the formation of dust. This would probably be the ideal solution if other means than drilling, shooting, or wedging could be found for breaking rock. However, no such practical means are now available. Wet drilling does accomplish this to a certain extent by laying the dust the instant it is formed, and several different types of drills are now available. The more important of these are: (a) Standard water-type drill, putting both water and air down the drill steel; (b) vented water-type drills when water and a small amount of air are directed down the drill steel; (c) drills vented with a special tight connection between the tube and drill steel; (d) standard solid piston-type drills when no axial hole is striking the end of the shank. This uses a separate water box to push all water at pressure and no air down the steel; (e) any of these wet drills in addition could use soap solutions or other chemical substances to aid the water in wetting and laying the dust; (f) also any of these types of drills are considerably improved by providing a suitable number of blows of proper force and correct speed of rotation to give maximum amount of large-size chips in the cutting.

2. Provide a clean supply of air for breathing purposes. This is accomplished for underground work with certain types of respirators. That is, respirators provided with reducing air line or to a separate supply of low-pressure air with intake brought in from the surface. Also respirators of the filter type with renewable or cleanable filter elements on each man are sometimes found effective.

3. Ventilate to change the general air rapidly enough to keep the dust content in the air to a suitable low figure.

4. Control the dust at the source. This can be accomplished by either general or direct collection probably considered the most effective and practical method. (a) General collection of the dust consists of dust collectors in the approximate vicinity of the source of dust and pneumatically conveying the dust-laden air to large filters, then discharging the clean air back into the working area, using either mechanical filters or electrical precipitation; (b) direct collection of dust means collecting all of the dust at the point of discharge into the work area such as at the collar of the drillhole and depositing it in suitable containers.

Two methods now considered are the dusttight connection between the rock face drill steel and the suction tubing and a loose mechanical fit between the rock face steel and the suction tubing. The first mentioned or tight connection necessitates dry drilling with enough air forced down the drill to clean the hole and offers mechanical difficulties to maintain the tight fits on the uneven surfaces encountered in rock-drilling. It also has the advantage that this type of dust collection can be used with either wet or dry drilling. The amount of suction necessary to pick up the dust particles will not detract the flow of muck and water from the drillhole, but will effectively pick up all the dust and fine particles. Wet drilling is often considered necessary on account of the nature of the rock and,

together with a dust-collecting suction device, is required where very low dust counts are to be obtained, particularly in a confined working place with limited ventilation.

However, dry drilling can be used underground with this type of dust collection (where general ventilation is good) or for outdoor work and low dust counts maintained.

Dust Control in the Foundry Industry

The interest of the foundry industry in silicosis is indicated by three papers, entitled "The Dust Problem in the Foundry Industry", "Legal Aspects and Employer Responsibility", and "Enlistment of Foreman and Worker Interest in Keeping a Clean and Orderly Foundry", delivered at the convention of the American Foundrymen's Association in 1933. In the first paper mentioned Meiter (296) stated that silicosis may be prevented in general, by reduction of dust to a safe concentration and by initial and periodic medical examinations. Dusty plants can be cleaned thoroughly, he said, by the following methods: Use of water under pressure; compressed-air blowing; use of brushes and brooms; vacuum-cleaning; and use of air and water under pressure. He recommended elimination of dust at the source, which is of great importance, by the following procedures: Good housekeeping methods; elimination of bad practices; maintenance of equipment in a dusttight condition; use of suction systems; isolation of dusty processes; special ventilation arrangements for special processes; and supplying protective devices to workers. He said that the desired results could not be obtained by using one of these methods; the particular combination which will be successful in one plant may not be in another. These methods, therefore, must be adapted to the specific problem that arises in different groups. Special attention was drawn to the method of abrasive-cleaning and the suggestion made that the efficiency of these methods should be tested periodically by screen-sampling. Meiter (296) stated that dust problems in industry can be controlled by proper supervision and education, but that it is essential that both employers and employees realize the importance of the problems and the necessity for combined efforts in reaching their solution.

From an investigation of health hazards in the foundry industry at the request of the Wisconsin Manufacturers' Association, McConnell and Fehnel (102) concluded that, although foundrywork at present may be considered a hazardous occupation, there are available well-designed equipment and protective devices which, if used and maintained, will prevent undue exposure of foundrymen to hazards injurious to health. They found that the usual ventilation of foundries is by windows. A system of forced draft, either for general ventilation or for the ventilation of individual rooms, sometimes is used. General ventilation is supplemented, as a rule, by ventilating hoods at specific points. The ventilation of foundries, so far as supplying pure air for breathing is concerned, is quite difficult on account of the smoke, fumes, and dust incident to foundrywork. Where these can be collected and exhausted at the point of origin the problem of their control is simplified, but the investigators state that unfortunately they cannot always be so controlled. They found that the introduction of new methods, new apparatus, and new

protective measures has greatly ameliorated the atmosphere in foundries. Mechanical cleaning of castings in conjunction with suitable exhausts, use of tumbling operations and dusttight sand-blast rooms, hydraulic washing of castings, and provision of positive air-pressure helmets for workers engaged in sand-blasting are all measures designed to control the health hazards resulting from dust inhalation. Certain types of foundrywork must be done by the older methods, particularly in connection with large castings where production is too infrequent to warrant the expense of sand-blast equipment or where the size or character of their cores will not admit the use of sand-blast equipment. However, it was found that most of the dust incident to foundrywork results from defective equipment and lack of proper maintenance.

The health hazard from the inhalation of foundry dust results chiefly from three foundry operations (102): Sand conditioning and conveying, shake-out operations, and cleaning operations. Even when sand conditioning and conveying reduce to a minimum the distance the raw materials and sand are conveyed, the dusts created by these operations are distributed throughout the entire foundry. Marked improvement as regards dustiness would be noticeable if these operations were carried out in a separate department completely isolated from the foundry proper, and considerable dust could be confined by enclosing the sand conveyors. Shake-out operations raise clouds of fine silica dust which penetrate the entire foundry atmosphere and expose practically every worker to the dust. If the heavy castings were shaken out in a separate room fewer workmen would be exposed to the dust; with small castings the shaking-out can be done over a grate attached to an exhaust or in a separate room. If the operation was begun at the end of the working period the least number of workers would be exposed to the resulting dust, and enough time would elapse for the dust to settle before the next working day was begun. Castings sometimes are chipped, ground, and sand-blasted in a separate department, but it is common practice to conduct such operations at almost any convenient location in the foundry proper. Hoods and exhausts for trapping dust arising from grinding wheels, mechanical maintenance of a good type of sand-blast cabinet, and use of an efficient type of respirator by the operators will aid greatly in safe-guarding the workers.

Methods of Control in Granite Industry

Bloomfield's (297) study of the efficiency of dust-removal systems in two modern granite-cutting plants revealed that graniteworkers are exposed to highly injurious dust (containing about 35 percent quartz) of a potentially dangerous size (virtually all the dust examined was less than 10 microns in diameter). Tests showed that the systems of dust removal in use at these plants, if maintained and used properly, can keep the dust concentration below 10 million particles per cubic foot of air. It was observed during the course of the investigation that many of the hand pneumatic-tool operators did not use the exhaust pipes furnished them; they permitted the suction hose to hang close to the ground so that pieces of granite were picked up by the exhaust and soon clogged the trap next to the metal duct; such practice obviously results in a diminution of the exhaust velocity at the working surface and an increase in the amount of dust in the air of the plant. It was noticed also that the suction devices in use with the surface cutting machines often

were not used at maximum efficiency; the adjustable hoods were lifted too high from the stone, so that much of the dust generated in surface cutting escaped into the room instead of being removed through the exhaust hood. Many surface cutters either blew dust off with the compressed-air supply or brushed it off the stone without first wetting the stone with water. One of the most common abuses practiced by granite workers is blowing dust off a stone with the exhaust port of the hand pneumatic hammer. Carvers and letterers, particularly, claim it is necessary to resort to such means to remove the fine dust from the small crevices in the design being carved on the stone. In testing the amount of additional dust created by such practice it was found that a carver who blew the dust off the stone twice every minute produced 39 million particles per cubic foot of air. When he did not remove the dust by blowing it off with compressed air 29 million particles per cubic foot of air were produced.

In addition to observing certain precautions in the use of suction devices Bloomfield (297) stated that the study indicated considerable improvement in the maintenance of these systems and recommended that each plant delegate some man familiar with the ventilation system to inspect the various dust-removal devices weekly to determine whether or not pipes are clogged by granite chips and to see that all dust traps are kept free of excessive material and that leaks and imperfections in the ventilating pipes are repaired. Determination of air velocities at the surface of exhaust hoods by a vane anemometer would indicate whether each dust-removal device is functioning properly.

According to Smith (298) stonecutting is done in some 200 plants in and about New York City; most of these are small, each employing an average of less than a dozen men. In normal times work is steady and done partly in the open, the shed as a rule being open on at least one side. Conditions of work thus differ from those in some States where more severe winters force work to be done mostly in enclosed sheds. Many employers about New York City therefore believe that stonecutting in this vicinity is less harmful than in New England; however, studies in two representative stoneyards showed that dust counts exceeded limits of safety in all operations except machine polishing and sawing, and examination of 125 granite cutters in these yards revealed evidence of silicosis in 78 (62 percent) of the group examined, 33 percent being in advanced stages. Smith states that this serious hazard can be controlled by the well-known methods of local exhaust ventilation, direct protection of workers by masks, and good housekeeping, if there is a will to do so. She refers to the system of control (local exhaust ventilation) devised by Hatch, Drinker, and Choate (299), which has demonstrated its ability to maintain low dust concentrations in a large, entirely enclosed stoneyard. She also calls attention (298) to the fact that the cost of such equipment is not prohibitive, and its principles do not differ from the well-known principle of exhaust ventilation wherever applied; however, the method requires a certain amount of intelligent cooperation from the worker to attain the best results, and the employer himself should be interested and alert. Next to exhaust ventilation and direct protection by masks, good housekeeping is considered essential in controlling the dust hazard. This heading covers proper maintenance of equipment and the avoidance of unnecessary dust exposure that results from ill-considered arrangements. As example of the latter, Smith (298) cites one

of the yards investigated; here sand was reconditioned by screening adjacent to the sand-blast cabinet, so that a number of nearby workers were exposed to the dust created thereby. As a result of poor maintenance and housekeeping, the sand-blast cabinets leaked, and dust exhausted from the surfacing machines under certain conditions blew back into the yard. As in the care of masks, attention to such details must be the business of somebody who understands the hazard and wants to control it.

Beyer (295) states that for self-preservation plants in the dusty industries must begin a comprehensive program of improvement immediately that will at least check the development of new cases of industrial disease. He mentions the following important points confronting plant managers who are struggling with this problem:

> In general, the most reliable way to correct a dust hazard is to install exhaust equipment that will capture the dust at the point where it is generated. This has been worked out very effectively for such equipment as grinding and buffing wheels.
>
> Unfortunately a complete system of dust-collecting and separating for a large department costs a lot of money--more than many plants feel they can possibly afford under present business conditions.
>
> For such cases there may be other alternatives or temporary expedients that will at least tide matters over until improved business conditions warrant the installation of a permanent dust-removal system.
>
> For instance, the manager of a plant recently visited by the writer stated that they had already spent $80,000 in exhaust equipment and had not yet fully solved the dust problem. In this industry the use of oil which has been sprayed on the material in some cases in the past to improve its handling in the machinery and processes offers a promising solution of of the dust problem. Dust counts in some plants using the oil show reductions of 90 percent or more in millions of particles per cubic foot, and if further tests corroborate these results it offers a simple and comparatively inexpensive method of correcting the dust hazard in one industry.
>
> In other operations, such as the shaking out of foundry castings, it may be possible to do this work at night, by men who are protected by respirators, and thus eliminate a common exposure to employees engaged in other operations in the same room. The use of enclosed mechanical conveyors and material conveyors and material handling systems, properly exhausted, instead of the old individual hand methods where the workers were brought into close contact with dusty substances, offers a solution in other cases.
>
> The treasurer of one concern with whom I recently discussed the hazard of his foundry said, "Maybe we have the answer right here", and he brought out the design of a machine which was fabricated entirely from sheets, plates, angles, and other structural shapes, riveted and welded together, which would entirely eliminate the castings of which it was largely composed in the past.

Where the dusty work is in a permanent location and too great freedom of movement is not required the air-fed respirator may give satisfactory results. For cases of temporary dust exposure, as for sweeping and cleaning up dust, the improved types of filter respirators may be adequate. In some cases substitutes may be found for the substance causing the trouble. ***.

The use of water to overcome dust hazards is one of the first suggestions that is usually made. I recently tried to explain this problem to an industrial manager and, after telling him that the dust which causes the trouble is less than 10 microns in size, a micron being about 1/25,000th of an inch, and being encouraged by his nods which seemed to indicate that he was following my explanation perfectly, I was a little disconcerted at the end to have him say, "Why can't you get rid of those microns by washing the air?" Apparently after all my efforts he still thought a micron was something like a microbe!

Where exhaust equipment is installed poor maintenance of these systems whereby their value is reduced or entirely vitiated is altogether too common. An inquiry in a plant recently as to how the dust-filtering apparatus was working brought the reply, "Fine--we haven't had to even look at it for 6 years!" When we climbed a ladder to the roof to see this miraculous equipment a touch on the screens shook a pailful of dust from the "clean" side of the separator. ***.

And so, to summarize the results of this brief survey of the mechanical control of occupational disease hazards, it is the opinion of the writer that chiefly in this direction lies safety from some of the most serious diseases, if one also includes rearrangement of the processes under "mechanical control", in contrast with the "medical control."

While agreeing that medical supervision of new prospects for employment is of primary importance, in order to prevent placing new employees who have some physical impairment in a position where they will quickly break down as a result of the work hazard, and granting the value of medical follow-up of employees subjected to exposures such as lead and benzol, which bring about a temporary condition that may be checked by medical supervision and a change of occupation, it seems evident that in the most serious industrial disease hazard, that of exposure to silica dust, chief dependence must be placed on elimination or control of the dust.

Section 4. - Medical Control in the Prevention of Dust Diseases

If the problem of dust control is to be solved engineers and doctors must cooperate with each other as well as with management and labor. In an article entitled, "Health and the Engineer", Whipple (300) in 1918 called attention to the unique opportunity of engineers to become a great social force in bringing about harmony between work and workers and improving working and living conditions of the workers. He did not feel justified in saying that such work had been entirely neglected but that health-protective measures, provision for housing workmen, installation of safety devices, and welfare work

of many kinds had not been done as a matter of course but rather by compulsion of law or by the benevolence or patronage of employers. He also criticized the laboring people because they did not appreciate these measures as great factors in their problem, their chief aim being more pay for less work. He said that engineers fill an intermediate position between the employers and the employees, and to do this properly they needed to broaden their idea of efficiency from that of the most work for the least cost to include benefit to constructing laborers as they build and to the workers who are to use the constructed plant, in this, the hygienists must cooperate and show engineers what to do. He stressed the need of cooperation among all who have to do with human health. Zangger (301) observed lack of cooperation and even interference in each other's work among technicians and medical men; there should be no sharp line of distinction in the knowledge of protection against industrial diseases among doctors and technicians--each should have some knowledge of the other's work.

The literature contains comparatively little information on medical control of dust diseases, except for the work done on the Rand in South Africa; this lack may be due in part to the attitude formerly taken by the medical profession toward industrial work. Davis (302) deplored this attitude as late as 1920, as shown by the following:

> The best of the medical profession have in the past looked askance at industrial work, because of lack of system and business methods in the average doctor's work. Most doctors are individualists in thought and action, and there is a generally prevailing idea that industrial medicine is performed by "down-and-out" doctors, at contract rates enforced by heartless corporations.
>
> The profession is changing its attitude as its members see what can be accomplished by organization and group practice as exemplified and demonstrated by various organizations now existent.
>
> On the side of business there is the awakening sense that cheap and inferior medical work is not satisfactory in any particular and is often disastrous and that the best medical talent should be procured. This presages the getting together of the best in medicine and the best in industry, to their mutual benefit.

In a recent discussion in England of the apparently sudden development of silicosis among the South Wales coal miners Moss (303) said that he could not imagine, somehow, that doctors in the country as a whole would have failed in the past to diagnose such a serious disability had it been prevalent. As mining conditions are much the same as in the past, he could not conceive that conditions could be worse on the whole, and yet all at once this disease was said to be springing up in South Wales. He wondered whether the increased liability of the South Wales miner to lung trouble was not due to a lowered standard of living there, compared with the rest of the country, and had no reference to the conditions in the mines.

The above statement calls to mind the conclusion reached by the Royal Commissioners appointed in England in 1862 (9) that the influence of dust was

subsidiary to many other adverse conditions in spite of the evidence of the miners themselves that dust was far worse than anything else with which they had to contend.

State compensation laws compelling medical and surgical treatment for injured workers emphasized the value of medical service in industry, and the growing realization of the menace--economical as well as physiological--of dust diseases in industry has been attracting the attention of outstanding members of the medical profession; the qualifications required for successfully coping with such industrial diseases are infinitely higher than those formerly considered sufficient.

Lauffer (304) has called attention to the health hazards within the industries, which industrial initiative should control; within the communities, which coordination of industrial and community health service can control; and within the scope of the individual, which require his personal initiative to combat successfully.

Physical Examination of employees

Probably the most important weapon in the medical control of dust diseases is the physical examination of the worker. Selby (305) described physical examination as the means whereby physicians acquire the information they deem essential to the procurement and maintenance of healthy, physically competent working forces. It is the basis of medical knowledge in industry and is fundamental to the successful practice of industrial medicine. The scope of the examination should be broad enough to enable physicians to gather the requisite information. It should therefore uncover defects and diseases that render employment hazardous to him who seeks it or to his fellowworker; it should uncover imperfections that contribute to inefficiency and diseases and substandard health conditions; in short, it should divulge the true condition.

Regarding the impression that the employment of healthy, physically competent workmen may imply the rejection of those who are not, Selby (305) said that the latter need not be rejected outright and deprived of the privilege of gainful occupation, as there are positions in virtually every plant of reasonable size that persons of varying substandard conditions of health and body can fill efficiently, to the profit of their employers and themselves. Only the manifestly unfit and the victims of communicable disease should be rejected--with rejection the last resort.

According to Burlingame (306) safeguarding the health of the employee is the one interest the worker has in common with the employer. From a study of the development of industrial relationships and contacts through a community health and tuberculosis demonstration over a period of years Armstrong (307) concluded that medical and nursing facilities in industry can be used to full advantage only if they are operated in close cooperation with the labor groups concerned. These facilities must be used with the primary object of fitting the man to the job, not as a device for rigid elimination of the unfit from industry. It must be recognized, however, that through the adaptation (or possibly elimination) of a few will come the protection of many.

In outlining the program which he followed in examining workers in dusty trades Sanders (308) said that the purpose of the examination was not so much to eliminate the unfit as to place workers in positions in which they seemed best suited. He emphasized that during the course of such an examination the worker's viewpoint on safety might be changed materially by taking advantage of the personal contact to inform his regarding the purpose of the examination program and what he himself could do to curb dust dissemination.

A large automobile-manufacturing company gives a preemployment medical examination and assigns a new employee to work that fits his condition. According to Cameron (309), disability does not necessarily bar him from a job, as is borne out by the fact that 20 percent of the workmen (12,000 in all) employed by this company are in the physically disabled class--some are blind, some deformed, and some are not very strong. Each man's work is selected to fit his case; tuberculous men have sheltered places in the open air, and by a system of medical transfers jobs may be changed at any time for reasons of health.

Britton (310) states that when a comprehensive plan for such service has been worked out as a part of the whole industrial-relations program a medical department in an industrial unit can be of greatest service both to management and employees and can and should be one of the strongest influences in cementing a cordial relation between industrial employees and management. However, such a plan requires a staff of the highest caliber, an adequate place in which the staff can work, and modern facilities for making accurate observations. This organization and equipment should be used constantly to assist in determining any industrial factor affecting the health of industrial employees.

At the meeting of the National Safety Congress in 1934 Adams (311) strongly urged employers to conduct periodical physical examinations but cautioned them against conducting these examinations with the sole idea of weeding out the unfit. "The chief value of such examinations," he said, "and for that matter the chief value of a medical department, is to fit each industrial worker to a job according to his ability to perform it without injury to himself or to his fellowworkers and with profit to himself and his employer. A byproduct of the examination is the record of existing disabilities which may be valuable in the prevention of subsequent false claims of disability from previous handicaps."

The first well-known, extensive, long-time use of the physical examination in connection with the prevention of dust disease was in the control of silicosis in South African gold mines.

All medical examinations of South African miners are conducted or controlled by the Miners' Phthisis Medical Bureau, a central body of whole-time government medical officials created in 1916. With regard to European miners the main functions of the Bureau have been:

1. To conduct an "initial examination" of all new recruits for the industry;

2. To conduct a "periodical examination" of each working European miner once every 6 months in order to secure the early detection of all cases of silicosis or tuberculosis which arise amongst the working miners;

3. To conduct a "benefits examination" of all miners or ex-miners who claim compensation in respect of the presence or suspected presence of silicosis or tuberculosis; and

4. To decide from the medical standpoint upon the claims of dependents of deceased beneficiaries.

The mine natives are given three medical examinations--a preliminary sifting in the recruiting area, a principal examination at the Witwatersrand Native Labor Association's depot in Johannesburg, and a supplementary examination by the mine medical officers. The aim of the periodical examination conducted or controlled by the Miners' Phthisis Bureau is to detect all cases of simple silicosis, tuberculosis with silicosis, or simple tuberculosis among the working miners and mine natives. The following summary indicates some of the results attained by these examinations (81):

A very important result of the initial examination in the case of European miners has been the gradual introduction since 1916 into the general body of working miners of a group of men of specially selected physique, whom we call the "new Rand miners" and who now number over 8,300, or 54 percent, of the whole body. ***.

From the purely preventive aspect the most important consequence of the periodical examination is the permanent removal from underground work of persons found to be suffering from tuberculosis or tuberculosis with silicosis, who are thereby prevented from remaining as potential sources of dissemination of infection. The number of cases of these conditions detected amongst European miners has fallen steadily during the past 10 years and does not now constitute a serious menace.

The preventive aspect of the periodical examination is of more importance as it affects the native mineworkers. ***.

The result of the examinations of mine natives discloses that simple tuberculosis and tuberculosis with silicosis taken together are decidedly more prevalent amongst them than amongst the European working miners. The reverse is true of simple silicosis. ***. The number of cases detected annually is considerable, and, so far as underground conditions are concerned, it is from the mine native that the menace of tuberculous infection arises both in the production of cases of frank tuberculosis and in that of early infective silicosis amongst European and native employees alike. Hence the necessity of continuing the campaign to reduce all possible sources of tuberculous infection in the mining population to the fullest practicable extent. ***.

From the years 1917 to 1920 the incidence averaged 3.5 percent, but the returns for these years were inflated by the inclusion of a considerable

number of "accumulated" cases of early silicosis which became compensatable as "ante-primary-stage" cases in 1919 to 1920. ***.

But the further drop which has since occurred to a figure of 1.76 percent in 1928 to 1929 is even more satisfactory. It represents a genuine improvement because it has been effected in the face of a continued increase in the number of older miners at work. ***.

The most striking evidence of improvement is seen in the returns for the specially selected body of men who have entered the industry since 1916 and whom we have termed the "new Rand miners." These men now number over 8,300 and are increasing year by year. Now whereas in the period from 1920 to 1925 the attack rate for silicosis amongst all miners who were working in their tenth year of service was 5 percent, amongst the "new Rand miners" working in their tenth year of service in 1928-29 it was only 1.3 percent. Part of this effect is certainly due to the better stamp of man of which the "new Rand miners" are composed. But if we allow an equal share to that factor this result is still remarkable. One cannot indeed anticipate that rates of this low order will continue when the "new Rand miners" enter the later periods of service, but there is no reason to suppose that they will even then reach the relatively high figures which the older miners have hitherto shown.

The second most extensive long-time use of the physical examination in connection with the employment and placing of workers in the mining industry was undoubtedly that in the Picher district in the United States (88,89) with the primary purpose of reducing the incidence of silicosis and tuberculosis among the miners and safeguarding their general health and that of their families. The employees voluntarily submitted themselves for examination with the understanding that all miners employed at the time, except those having tuberculosis and advanced silicosis, would be allowed to continue working. Men suffering with infectious diseases in the active stage were suspended until noninfectious. The examinations, continued annually for 5 years (1927-32), revealed that many of the men at work and applying for work had one or more diseases or physical defects; many had serious and in some instances contagious diseases. In all 44.03 percent had one or more diseases or defects considered serious enough to bear directly upon their work, compensation risk, or life expectancy. Certain physical defects and diseases were revealed as apparently predisposing causes of silicosis. So few cases of nasal obstruction were found that no definite conclusion could be drawn, but apparently both silicosis and tuberculosis showed a slight increase in men with this defect. This observation is confirmed by reports of a test made in Germany by Lehmann (312), who examined 426 noses; 241 of the miners were ill with lung troubles, and 185 were well. The noses were tested by blowing into them air laden with a fixed amount of dust and allowing the air to issue from the mouth while the breath was held. The dust content of this air was measured, and the percentage of the original content filtered out by the nose was determined; the healthy miners prevailed among the high percentages, the affected among the low percentages. Lehmann (312) recommends that no man be admitted to a dusty job unless he can pass such a nose test. His discussion of the results follows:

In all occupations in which a silicosis hazard exists it has been observed that individual susceptibility varies greatly. Whereas many workers become ill after only 2 or 3 years in a dusty occupation, others show only a trace or else no lung changes at all. The studies described permit us to utilize an important (and perhaps the most important) factor of this individual susceptibility. The figures given indicate that the silicotic susceptibility of workers with poor nasal filtration is much greater than that of men with good nasal filters. Consequently it seems to us logical that jobs with a silicosis hazard should be held only by men with good nasal filters.

We do not know today to what extent nasal filtration can change in the course of several years. It is probable that, in connection with atrophic disturbances to the mucous membrane, a general lowering of the filtering action will result. It would, therefore, seem advisable to repeat the tests yearly. Then any worker who showed a general lowering of nasal filtering power and had thereby acquired an increased susceptibility to silicosis should be removed from his dusty job and placed elsewhere. The so-called "mouth breathers" are an especially bad risk and should be excluded from any task involving exposure to dust rich in silica.

According to Safety Engineering (313), the nose is a perfect apparatus for dust filtration to a certain extent; if the nasal organ is functioning as Nature intended it will trap a large proportion of the dust breathed and keep the lungs free and in good working order.

Tillson (124) has suggested that certain measures might be taken to increase the natural defensive reactions of the respiratory organs. He elaborates the idea in the following statement:

> As part of Nature's defense against the intrusion of dust in the system, a ciliated epithelium is provided as a lining of all air passages except the upper part of the nares (the nostrils), lower part of pharynx (the 4½-inch long alimentary and respiratory canal to the esophagus and trachea terminal), the bronchioles, and finally, the pulmonary alveoli.
>
> This epithelial structure is a layer of more or less columnar cells, on the exposed surface of each of which is a bunch of fine, tapering filaments with tubular channels opening at the tips. These cilia (hairlike processes) move in such a waving fashion as to produce a flow outward of the fluid which bathes them. They make a rapid stroke in the direction in which the action is to be effective and a slow return stroke; also, all cilia attached to any one cell or row of cells acts synchronously; furthermore, any individual cell begins its effective stroke slightly later than the cell lying internal to it. In this way a progressive wave motion is produced to carry toward the exterior dust or other extraneous matter which becomes entangled in the mucus that is deposited in the ciliated surface by numerous glands.
>
> Activity of the cilia is modified by almost any factor which affects protoplasmic activity, such as concentrations of oxygen, carbon dioxide,

hydrogen ions, and various salts; also, increase of temperature up to a critical value causes increased activity. But especially, the rhythm and rate are increased by mechanical loading from placing a particle on the mucus-covered tip of a cilia; and the hypothesis is advanced that the blockage of the tip opening of a blind tube increases the liquid pressure in the same and with it the increase of the flagellating activity of the cilia above their normal frequency of approximately 10 waves per second.

All of these factors are of interest when considering the preventive measures which man may devise to cooperate with and stimulate natural preventive functions. For example, if dust particles had the same sign of electric charge as the phagocytes, they would repel them and not be ingested to produce toxic effects. But could elimination be provided in some other manner? A deficiency of mucus or cilia activity might be overcome by artificial means and a more rapid and complete ejection of dust particles thereby be accomplished. A suitable electric polarization of dust particles might assure their repulsion of attraction to the cilia with corresponding ejection. Establishment of a proper acidity (pH value) in the respiratory tract might be effective.

The introduction of a hydrophillic substance with an effective surface (that is, one with an area large enough to accommodate the ends of chain-type molecules which may be held end-on to it) can initiate the process of a clot formation by offering plasma-wettable surfaces to which certain blood cells (as the thigmocytes) may adhere and over which they will spread to produce their rupture and liberation of their thrombin content to react with fibrinogen and produce a clot of fibrin. Powdered glass, quartz particles, bubbles of carbon dioxide gas, and pieces of tissue provide such surfaces and can cause that serious pathology called thrombosis, so often fatal in its results. Again, still another danger is created by the injection of certain mineral dusts into the systems.

Diseased conditions of the mouth (pyorrhea and missing and decayed teeth) may have caused the gastrointestinal symptoms which were the most common subjective symptoms mentioned by the silicotics in the Picher district.

The examinations at Picher indicate that syphilis apparently is closely related to silicosis, silicosis plus tuberculosis, and tuberculosis. Close correlation of the incidence of syphilis with uncomplicated silicosis indicates that syphilis may be a predisposing cause, and clinical observation leads to the belief that silicosis runs a more rapid course in syphilitics.

The Picher investigation also revealed that the percentage of uncomplicated tuberculous cases increased with each age group (between 60 and 69 years), but this finding does not agree with the known fact that the disease is more common in early adult life. The condition at Picher probably is due to the fact that many persons with arrested tuberculosis work for a time in the mines after returning from the high, dry climate of the West. Clinical experience has shown that these cases soon become active and often run a rapidly fatal course. One percent of all industrial workers are said to have tuberculous lesions in their lungs (314), indicating the advisability of examining applicants for work in dusty trades since such tuberculous lesions under unfavorable

conditions predispose to the development of tuberculosis in a year or less. An X-ray examination would reveal this condition, and the prospective employer would know definitely which workers would be unsuited to exposures that would favor the development of tuberculosis; those affected would thus be saved from exacerbation of their condition and also their coworkers from infection. In connection with the advisability of preemployment examinations the following instance mentioned by McCord (315) is interesting:

> Lately I have had opportunity to examine well-made X-ray films of applicants for work, without admitted previous exposure in industry. These persons were found to live and drive on dusty country roads made of flint. Approximately 50 percent of these young adults presented sufficient involvement in their films to be rated as "suspicious" in relation to pneumoconiosis. Given a few months exposure in a foundry any one might hold himself eligible for claims against his employer alleging dust lung disease.

According to Flinn (316), the steady rise in the rate of attacks of influenza in cementworkers would seem to indicate that the mucous membrane of the respiratory tract has been injured to the extent of lowering body resistance to such attacks; if the mobility rate of the lungs of workers in the dusty trades were tested it probably would be found to decrease with the length of exposure at a rate unaccounted for by the decrease due to age. He found that after working 8 years in cement men showed a definitely lower vital capacity than workers in 10 other occupations or than men who had worked less than 2 years in cement; army regulations discard a man 68 inches tall as a tuberculosis prospect if he shows less than 2 inches of mobility. This would indicate the value of periodical examinations of workers in dusty industries to determine whether the vital capacity is being affected by the occupation; Flinn points out that only by studying the individual himself from time to time can any conclusion be reached in this matter.

The same idea was expressed in 1916 in the General Report of the Miners' Phthisis Prevention Committee (317):

> That man who is best suited for underground work is one with a good and sound physique and <u>with a good reserve of respiratory capacity</u>. A man of poor physique may be sound in the sense that he is not actually diseased, but he has commonly a low power of resistance to infection, and if he has a poor respiratory capacity he has so much the less available respiratory reserve.
>
> Age is also of importance. We doubt the economic wisdom of accepting for underground work for the first time any man of over 45 years of age unless his physique is unexceptionable. There is normally in persons round about 50 years and over a tendency to an increasing reduction in the expansile power of the chest wall, and a proneness to bronchitis and emphysema. Dr. Watt has called attention to the fact that there is apt to be an increase in the amount of fibrous tissue in the lungs as age advances.

These facts are of importance, because a man with a good chest and a good reserve can carry, without inconvenience or loss of health, an amount of fibrosis which might seriously affect one with a poor reserve, or a chest becoming rigid through age.

All persons who have signs of a tuberculous taint, even if it be latent, should be rigorously excluded.

Cases in which one or other of these factors have been present are familiar to those who have to examine claimants for compensation under the Miners' phthisis Act, and it is noticeable that, in many such cases, the duration of underground service has been comparatively short.

We would recommend that a uniform standard in regard to the degree of physical fitness required of a man on first application for underground work should be arrived at, and a simple examination form should be drawn up for use at such examinations. Such a policy would be useful also in detecting physical defects or the results of previous injuries, which would be of importance for identification and, incidentally, of value medicolegally.

We would suggest that examination of all men applying for the first time to undertake underground work should be conducted by a central examining board, an arrangement which would conduce to uniformity and relieve mine medical officers of a duty which is often unpleasant when applicants have to be rejected.

The results of the industrial survey made by McCann (266) in Rochester, N.Y., in connection with a so-called "silicosis racket" revealed dangerous quantities of dust in the air of a number of plants; but the most disturbing result was the lung conditions revealed by the X-ray examinations. Only about 30 percent of the lungs examined could be considered normal; almost invariably the possessor of the normal lungs was a machinist, watchman, officeworker, or a very new and young employee. McCann (266) states, however, that it must not be inferred that 70 percent of the employees in the industries surveyed have silicosis or pneumoconiosis; about 40 percent of the total exhibited pathological changes in the lungs which did not in the least resemble those of silicosis or pneumoconiosis. This group comprised all sorts of abnormalities such as evidences of chronic nontuberculous infections of the lower lobes, bronchiectases, pleural adhesions, and the fibrosis of heart disease accompanied by abnormal shadows of the heart and large vessels. A certain amount of adult tuberculosis--some healed, some apparently latent, and some undoubtedly active--was found. In fact, this large group showed all the common types of pulmonary disease that could be found in any group of similar ages. It included all persons whose lungs showed a diffuse reticular fibrosis with increased density of the shadows at the root of the lungs; all such cases were classes as suspected pneumoconiosis. If the reticular markings tended to agglutinate or suggested nodular mottling the diagnosis was changed to "probably early pneumoconiosis"; if the nodular mottling was clear-cut, a definite diagnosis of pneumoconiosis was made, in spite of McCann's firm belief that this diagnosis should never be made on the basis of history and X-ray examination alone, because employees whose chest films revealed this condition could sue for damages with great probability of success in a trial by jury.

Ogden (313) recommends a very complete history of all new employees because he claims that malnutrition of idle workers during the depression has increased susceptibility to silicosis and other industrial diseases.

McConnell (319) believes that thorough physical examination at the time of employment and at regular periods thereafter is the best method of eliminating diseases caused by dust in industrial establishments. The effectiveness of dust-control measures in preventing dust diseases can be determined only by careful physical examination of the worker so exposed under guidance of competent medical supervision. He states that the benefits that accrue to the employer and employee alike as a result of physical examination of all applicants for employment, as well as periodical examination of those already at work, would indicate very careful consideration by industry of a program for control of sickness. Such procedure protects the employer from engaging an applicant already physically or mentally impaired, who later may claim disability for his condition even though it was not associated with employment or was contracted during a period previous thereto. The applicant's physical and mental condition is thus established, and by keeping records of his subsequent illnesses and accidents the question of responsibility for injuries and sickness incurred during employment never need arise. He also states:

> The diagnosis of the diseases resulting from industrial hazards and the extent of disability incurred obviously should be entrusted to medical men specially qualified for this work with facilities for adequate radiological examinations. Disputed cases should be referred to a board composed of trained personnel capable of coordinating the medical, radiological, and pathological examinations as well as the results of scientific investigations. The action of such a board of specialists should be final.

McConnell (319) outlines a plan for medical control of all phases of the dust hazard as follows:

1. Establishment of a medical department adequately equipped.
2. Routine examination of all applicants for employment.
3. Rating and placement of applicants.
4. Periodical physical examinations.
5. Provision for the disabled.

Bateman (270) states that next to ventilation and the laying of dust the most important measure in the prevention of silicosis is careful selection of the type of men to be allowed to work in the mining industry. This requires a rigid initial examination, which should include a complete physical examination and X-ray. Men with a chest indicating susceptibility to tuberculosis and silicosis could thus be eliminated. Uncomplicated silicosis is not a big problem, but silicosis and tuberculosis combined represent a very real problem, and particular attention, he believes, should be paid to withdrawal from the

mining industry of men with tuberculosis. He also recommends that employees' living quarters be supervised to see that the men are not exposed to tuberculosis at home.

Clinical and X-Ray Examinations

The studies conducted at the Picher Clinic (88) included collection of personal data such as age, marital status, and contact in the home with tuberculous patients; past history of disease; occupational history, including past and present occupations, total years worked, and years worked in dusty operations; present history detailing subjective symptoms experienced by the examinees; physical examination, including such objective data as appearance, development, weight, height, pulse rate, respiration, blood pressure, and condition of eyes, ears, nose, throat, skin, chest, heart, and other organs; X-ray examination of the chest; and laboratory examination, including blood count, Wassermann test, and microscopic findings.

According to McNally and Bergman (320), a history of the exact occupation and exposure of each workman in the silica-containing dust, a complete physical examination with the symptoms, and X-ray pictures are absolutely necessary. They state:

> Just as in the case of bronchitis, the connection between the disease and dust inhalation must depend upon an intimate knowledge of the occupation followed, of the exposure to dust, and of the mortality prevalent in that occupation. A correct diagnosis is of importance because, with the known tendency to a fatal termination, every case from its onset however apparently slight must be considered serious and treated accordingly.

Fisher (321) suggested that the cases of silicosis in the South Wales anthracite fields might be explained by the fact that the miners became chilled after the shift during the trip to the surface in cold intake air, the resulting bronchitis breaking down the natural mechanism by which dust is eliminated from the bronchial tubes and lungs. With the impairment of the dust-eliminating mechanism of the respiratory system dusts that normally are harmless either because of the rapidity with which they are removed or because of their low silica content tended to accumulate and produce fibrosis and diminished efficiency of the lungs. These facts led him to believe that the "nonindustrial" medical history of a youth who intended to work in dusty parts of a mine, such as conveyor ends, hard headings, or machine-cut faces, should be considered, as bronchitis and bronchopneumonia might facilitate the entry and obstruct the exit of fine dust particles. Fisher (321) also recommended that in view of the fact that damage to the respiratory system through bronchitis interferes with the dust-eliminating function of the lungs men who suffer from chronic cough or acute bronchitis should consult a doctor before taking up or resuming work in high dust concentrations, particularly in areas where many cases of silicosis occur.

Cook (322) stressed the vital importance of the radiological aspect:

The many varied shadows met in the chest that so nearly simulate each other make all avenues of diagnostic aid welcome by all well-meaning and open-minded medical consultants. One sees a great many confusing shadows in many of our respiratory conditions that may be so familiar by long and careful observation that something of less importance that may be a contributor is apt to be overlooked.

An opinion based upon roentgen evidence alone is of about the same value as an opinion based upon clinical findings alone. Without a careful history both lose much of their worth. Combined with other evidence, however, it may be of great value--without a doubt it is capable of revealing changes in the lungs which cannot be demonstrated by any other method.

In difficult cases, or those in which physical signs are absent, the roentgenogram may be the confirmatory evidence upon which a diagnosis is made--and in certain well-defined cases it may give a more accurate picture of the extent and distribution of the process and in this way give aid both to the prognosis and the treatment of the case.

Unfortunately, very few roentgenologists are well-trained clinicians. It is perhaps equally unfortunate that few clinicians have sufficient knowledge in interpretation of roentgen findings.

The cooperation of both clinician and roentgenologist, or the combined use of a single investigator, will obtain better results. The most careful and painstaking history often fails to reveal some of the most profound and complicated films that are met. A scoliosis may displace the heart or great vessel and give a peculiar shadow that can easily be misinterpreted.

All examinations should be supplemented by a careful fluoroscopic examination.

It is therefore essential, before making an ultimate diagnosis, that the history be carefully studied relative to exposure, length of time, and type of exposure. Many times I have been called to see patients with definite pneumofibrosis who had never been exposed to any type of industrial hazard.

In view of the present situation, many possibilities have been opened for the questionable unemployed to remember that at some time he was employed in a semihazardous occupation. The finding of some of the many types of lymph block fibrosis--this aided by the ever-willing legal vulture--has brought many nonindustrial contracted conditions into the courts of compensation.

According to Gardner (323), the roentgen examination requires good films, expert knowledge, and experience. A tuberculosis expert reading silicosis plates would observe the pneumoconiosis signs and, after consultation and study, acquire knowledge of its type and degree. Physical signs of pulmonary infection are few and seem insignificant unless the silicosis shows complication by infection.

The following statement by Landis (324) indicates the difficulties encountered in the diagnosis of respiratory diseases among anthracite miners:

> The interesting thing is that a roentgenologist who is out of these local spheres where you see the dust cases, particularly in the second stage where it looks as though you had thrown a handful of snowflakes against the film, almost invariably makes a diagnosis of miliary tuberculosis. In the third stages they will almost invariably make a diagnosis of advanced tuberculosis. ***.
>
> So far as the complicating tuberculosis is concerned, even the shrewdest reader of X-ray plates will be deceived, very often as to whether there is a complicating tuberculosis or not in a given case, so that you are driven back in many cases, though some are perfectly obvious. There is no difficulty in telling tuberculosis superimposed, from the X-ray picture, but in many of them it gets down to the question of sputum examinations. If the sputum is consistently and repeatedly negative, you are safe in assuming you are dealing with a plain, straight case of pneumoconiosis. Perhaps in autopsy it will show a small focus which is incidental and has no bearing on the situation whatever.
>
> We have a man at the White Haven Sanitorium now who has had 4 years' experience in examining a very large number of these cases of pneumoconiosis and only within the last 6 months, in spite of the fact that he has seen so many of them, he had 1 case in which he said there was complicating tuberculosis, and repeated sputum examinations failed to establish it. Another which he said showed no evidence of tuberculosis was taken later and showed tuberculosis.

Similar difficulty is encountered in making a diagnosis by the physical examination alone. On this point Landis (324) said:

> There is another curious thing and that is that on examination of the chests of these people, from the standpoint of physical diagnosis, in spite of the fact that the X-ray film will show the most dreadful lot of changes in these lungs, from the physical signs you get next to nothing. You may not get a single, solitary thing. ***.
>
> Within the last 5 years (and I am not certain that it does not apply even today) pneumoconiosis rarely if ever figures in either morbidity or mortality results. It is buried under all sorts of guises--tuberculosis, chronic bronchitis, pleurisy, etc. Furthermore it has more of a local interest. I mean local in the sense that there are men living in localities who by no possible chance practically ever run into this condition which in other localities is extremely common.
>
> I am reminded that about 13 years ago I gave a clinic before the medical students on pneumoconiosis and didn't give the matter any particular thought until the morning, when I thought it would be an easy matter to get sufficient X-ray films from our X-ray laboratory to illustrate what I had to say. To my amazement, when it came time to get them although the

Peter Brigham Hospital had been in operation for 8 years, they had just 1 pair of X-ray films showing pneumoconiosis. That was from a Spaniard who had worked in copper mines in Chile and who had been admitted to the hospital for something else, but the pneumoconiosis had been discovered accidentally.

It so happens that this condition with me is of a monthly occurrance. For the past 25 years I have been on the visiting staff of White Haven Sanitorium which is situated on the edge of the anthracite coal fields. At the present time, and for the past 4 or 5 years, all of the cases of tuberculosis of Luzerne County are sent to that sanitorium. It doesn't make any difference whether they have tuberculosis or not, the astonishing thing is that 60 percent of the miners I sent in under the belief they had tuberculosis are suffering from plain, straight pneumoconiosis. Every time I go up there--every 2 weeks--I find committed to my service from 1 to 3 of these miners. ***.

If you were to go to Wilkes-Barre General Hospital, into the X-ray laboratory where many of these men are X-rayed as a matter of routine--where they are admitted for fracture of the leg or arm or minor disaster--men who have no respiratory symptoms at all at that time--you would be perfectly amazed and appalled at the number of them who show perfectly definite changes in the lungs.

The following technic was used in the radiographic work at the Picher Clinic (88): All radiographs were taken at a distance of 36 inches, using $\frac{1}{2}$ to $\frac{3}{4}$ second of exposure, 55- to 85-kilovolt peak, at 30 milliamperes. The thickness of the chest was measured in centimeters with a pelvimeter. The kilovolt peak was regulated to compensate for varying chest thicknesses; the milliamperage, distance, and time remained the same. In chest radiography intensifying screens are a decided advantage from the standpoint of contrast, as a much lower penetration is permitted with the necessary time, distance, and milliamperage. Fifty to 100 kilovolts or more were used; most of the pictures were made under 85 kilovolts. When the work was begun the distance used was 72 inches and the exposure $\frac{1}{5}$ second. Motion was so great that only a few hundred films were made at this distance. Most of the work was done at 48 inches with an exposure of 1/10 second. All electrical installations were 25-cycle, the current emanating from one large plant which supplies 200 to 300 mines. The burden on the current, even with a transformer installed at the clinic, gave such marked fluctuation that comparable pictures were obtained with great difficulty.

Pancoast and Pendergrass (325) have published two reports on the equipment required and the exact technic for the X-ray examination of important cases of silicosis. They stress emphatically the necessity for a most careful technic in such examinations and the necessity for observation of the most exact details. They describe the positions to be assumed by the patient to give the most satisfactory films and the equipment necessary for the essential exposure factors. They make the following comment:

It is fully recognized that the above suggestions are the ideal. There are many times when it would be impossible to employ such an elaborate method of examination both because of the time and economic factors.

It is quite possible that the time will come when it will be necessary for industry to make routine roentgen examinations of the chests of all men seeking employment in dusty occupations. This must be performed adequately with the least amount of expense. It seems reasonable to believe that a careful fluoroscopic examination would exclude the presence or absence of 90 percent of tuberculous lesions. It could demonstrate silicosis at least of the nodular type. Wherever there was the least question of doubt, a single film of the chest could be exposed, and if this was inadequate steroscopic or even additional films could be made. The ideal procedure would call for at least a single film of the employee before beginning work. This would not always be possible, if, for instance, there was a demand for 200 men to be put to work at once. With careful fluoroscopic examinations, however, it would be possible to study a large number of men in a short period of time and exclude any with gross evidence of disease.

In follow-up examinations similar methods can be employed, the examiner using his best judgment as to the advisability of obtaining the film record. Each examiner should bear in mind that the fluoroscopic examination is not a tangible permanent record as are properly exposed films, and in order to protect the employee and employer one should have a permanent record. It should be borne in mind that such records (single film) would be of little or no value in case of subsequent legal claims.

The following rules and regulations dealing with the health of workers exposed to the silica-dust hazard came into force in connection with workmen's compensation (Silicosis, Acts of 1918 and 1924) in Great Britain in 1925 (326):

> All workmen employed in the industries shall be examined by one or more officers of the medical board at the prescribed intervals, and if on such examination it appears to the medical board that the workman is suffering from silicosis or tuberculosis or silicosis accompanied by tuberculosis to such a degree as to make it dangerous for him to continue work in the industries, the board shall suspend the workman from further employment in the industries and shall certify accordingly in the prescribed form.
>
> Any workman newly engaged by an employer and not excepted shall, unless he has already been examined under this scheme within the preceding 12 months, submit himself for examination by a member of the medical board or other duly appointed medical practitioner before the end of the first month of his employment or in exceptional circumstances within such extended period as the medical board may authorize; and if on such examination the workman is found to be unsuitable for work in the industries by reason of his failure to satisfy the requirements with respect to physique prescribed herein, the member of the medical board or duly appointed medical

practitioner shall suspend the workman from further employment in the industries and shall certify accordingly in the prescribed form.

For the purposes of this paragraph the requirements with respect to physique shall be as follows:

1. The chest must be at least of average development with satisfactory expansion and there must be no deformity or obstruction of the upper air passages or elsewhere which interferes with respiration;

2. There must be so signs of present or past disease of the lungs or heart; and

3. There must be no signs of present or past tuberculosis of any region.

On March 26, 1935, the Workmen's Compensation Law of North Carolina (327) was amended to include some occupational-disease features, among which were physical examinations for prospective and present employees engaged in the dusty industries, silica and asbestos industries; a medical committee to make examinations under the supervision of the industrial Commission; removal of employees in the early stages of disease; vocational training for those removed. According to Safety Engineering (327), this bill was drafted after many conferences between employers and employees. The bill includes a list of specified diseases and conditions as constituting occupational diseases within the meaning of the act.

Treatment of Silicosis

There is no cure at present known for silicosis, or at least no treatment has been discovered that prevents the progressive development of the characteristic fibrosis after it has started in the lungs. The deadly character of the disease was recognized as early as 1500 by Paracelsus (21); he mentioned in his book of miners' diseases that "the organism must be prevented from coming in contact with the metal emanations, for if the organism is once injured there is no cure."

At first it was thought that removal of the victim from further contact with dust would arrest the condition at the point of development reached when discovered. Although this may have been true in some instances apparently it is not generally so and according to Lanza (328) has not been borne out by recent experience. He states, however, that--

> The question of what to do for the silicotic patient is one of great moment, but recent experience has shown that removal from exposure and allowing the person to be up and around and not sending him to a sanitarium are probably best. Considerable research is being done in this country at Saranac Lake, the U. S. Bureau of Mines, and at Rochester; but not as much research is being done as should be when the economic importance of the present silicosis situation is properly taken into account. The importance of using specially selected medical boards cannot be overemphasized, and the successful experience of the British should be adapted in this country.

A study by Lawson, Jackson, and Gardner (329) of the afterhistory of 17 miners who had run drills 4 or 5 years for iron ore in the Blue Ridge Mountains revealed that they had developed distressing symptoms of lung fibrosis after discontinuing mining and living 4 to 8 years under good hygienic conditions. During their years of exposure they experienced only slight symptoms bearing upon the condition of their lungs. Dyspnea was a characteristic sympton, and a few complained of pleural pain; most of the men, however, appeared in excellent health although exhibiting limited chest expansion. The lungs of one of the men who died with chest symptoms about 8 years after leaving the mines showed fibrosis, with scarcely any alveoli remaining. According to the authors, the ore of these mines averaged about 35 percent silica.

According to McCord (330), incipient cases of silicosis will continue to develop after exclusion from the industry, but in some instances they live a long life. With regard to treatment he stated that there is no other than the symptomatic treatment required by the cardiac impairment, tuberculosis, and bronchitis that are likely to ensue, but there is no specific treatment or prospect of betterment in well-established cases.

"Protective" Dusts as Preventive or Curative Agents

For several years many investigators have considered certain dusts--coal, hematite, shale, limestone, cement, and clay--not only as harmless in themselves but as exercising a favorable effect when inhaled with more dangerous dusts. A few, however, have claimed that although some dusts are more dangerous to health than others all dusts are more or less harmful if inhaled in large enough quantities over long periods. The comparatively recent development of better methods of diagnosis and more thorough investigation of the physical condition of workers in dusty industries are gradually leading to a realization of the fallacy of using so-called "protective" dusts to prevent or cure diseases caused by the so-called "dangerous" dusts.

It was believed that "protective" dusts would cause the excretion from the lungs of such harmful dusts as silica by exciting a physiological process of elimination and that they acted in some way to prevent the development of tuberculosis. The idea evidently was based on the assumption that miners exposed to coal and certain other "inert" dusts were free from silicosis. Since about 1914 there has been considerable discussion and argument on this subject in the technical and medical press; a brief review of some of the arguments for and against the value of certain dusts as protective or curative agents follows:

Coal dust.- From the results of experiments made at the suggestion of Haldane with a view to classifying dusts as those that predispose to phthisis or other serious lung diseases and those that do not Mavrogordato (331) drew the following conclusions:

> The initial reaction is greater to "inert" dusts than to "dangerous" dusts, and their elimination is more rapid and more complete. The admixture of inert dusts such as coal and shale with dangerous dusts stimulates the initial reaction and brings about the elimination of more of the dangerous

dust than would be eliminated in their absence. With the dangerous dusts, the rate of elimination being slow, the dosage must be very small to avoid accumulation. The more free crystalline silica is from certain inert dusts, the less is the elimination and, therefore, the greater the accumulation in the lung tissues and the greater the fibrosis resulting.

In a discussion of the question as to whether the introduction of rock dust into coal mines to prevent explosions would offer a health hazard to the miners, Oliver (352) in 1920 stated:

> A coal miner's lung, if it is free from recurrent bronchial catarrh and is not too strongly impregnated with dust, can be fairly rapidly cleared of dust, whereas in the case of the gold miner and the Sheffield steel grinder and workers in some other dusty trades the particles of inorganic material remain in the lung.
>
> Since it appears, therefore, that the lung behaves differently toward different kinds of dust, we naturally ask ourselves why this should be so. Why do coal and shale particles disappear from the lungs of miners, while those of flint and quartzite are not removed, for in shale dust there is present a small quantity of quartz and the particles of dust are just as hard and angular as those obtained from the rock of South African gold mines? So far as injury inflicted upon the lung is concerned, it does not appear that the injury is caused by the crude chemical composition of the dust. It depends in all probability upon the power which certain kinds of dust possess of absorbing other substances. In my address to the Congress of Hygiene and Demography in Washington, U.S.A., in 1912 I showed, as the result of experiments carried on over a period of many months, that coal dust and pieces of coal varied in weight from day to day and that this was due to the power coal possessed of absorbing gas from the atmosphere: In a word, coal absorbs and evolves gas just as in ordinary respiration. It was quite different in my experiments with stone dust; with this there were no such interesting rises and falls of weight as with coal dust. Haldane has gone further and has suggested that insoluble dust particles are attractive and stimulating to the large pulmonary phagocytic cells in proportion to the soluble substances which the dust particles have themselves absorbed; that dust particles which have not absorbed such soluble substances or have done so only to a limited extent will be correspondingly unstimulating. Mavrogordato continued the experiments on Haldane's lines and allowed animals to breathe an atmosphere containing in suspension both coal and flint dust, with the result that when in due course he examined the lungs of animals which had inhaled the combined dust, the whole of the flint particles had practically been removed.
>
> It appears, therefore, that since experience and experiment alike show that the inhalation of coal and shale dust when breathed in moderate quantities is not followed by permanent injury to the lungs, since this kind of dust stimulates phagocytic activity, and since it appears that flint and quartzite particles which have reached the lung are also removed, there can be, therefore, little pulmonary risk incurred by coal miners when, in order to prevent explosions in the mines, stone dust is sprayed upon the fine carbonaceous dust which is so frequently present in certain mines.

In 1922 Collis (333) called attention to the lower incidence of phthisis claimed for coal miners compared to that for other workers. He quoted experiments of Wainwright and Nichols in which they exposed guinea pigs for about 2 months to coal dust and then injected a culture of tubercle bacilli. These animals were said to have developed "extensive tuberculosis of the abdominal viscera and of the glands around the tracheal injection, but the lungs were free"; control animals were said to have developed "extensive tuberculosis of the lungs and abdominal viscera." Such facts, according to Collis (333), have been cited to support the claim that coal dust in some way protects against tuberculosis. He stated, however, that should coal dust possess the power claimed for it workers at the coal face might be expected to experience a lower mortality from tuberculosis than other workers underground and others underground a lower mortality than those employed aboveground. The mortality data which he collected did not justify this anticipation but showed that throughout life the mortality from tuberculosis of men working at the coal face was higher than that for others below ground and, except for ages 20 to 34, inclusive, was higher than for those working aboveground; surface workers, on the other hand, up to 55 suffered more than others below ground. Collis concluded that "these data do not support the supposition that coal dust protects the workers against phthisis."

Two facts stand out rather clearly in the discussions regarding the comparative harmfulness of silica and other dusts. One is that silica is more dangerous because it apparently predisposes to tuberculosis more than other dusts. Irvine, Simson, and Strachan (129) state that "it is common knowledge that a lung affected by silicosis is peculiarly prone to become infected with tuberculosis." The second fact is that the mortality rate is highest in later years. According to Collis (334), the mortality rate for phthisis in the silica group always exhibits its highest incidence later in life--between 55 and 64--than does that for ordinary pulmonary tuberculosis. He states:

> This characteristic, which has been established from mortality records of definite silica groups, is important, quite apart from any light it may shed on the way in which silica acts. Thus, coal miners have always had a low death rate from phthisis, but this low death rate, since 1890 when statistical records first became available, has consistently shown a maximum incidence late in life, between the ages 55 and 64, at the very period picked out by silicosis.

The investigation at Picher (89) revealed that an average of 11.9 years was worked before first-stage silicosis developed and an average of 19.4 years before first-stage silicosis plus tuberculosis developed; second-stage silicosis plus tuberculosis developed in 18 years, and third-stage silicosis plus tuberculosis developed in 11.5 years (only 2 cases).

The United States Public Health Service in a recent investigation (335) found the prevalence of pulmonary tuberculosis among hard-coal miners below 35 years to be only slightly less than among male adults in the general population, but in the age groups above 35 the prevalence among the miners ranged from 2 to 10 times the rate among the males in the general population. These figures seem to emphasize the fallacy of concluding that because the incidence

of tuberculosis among coal miners is somewhat less in the early years (probably owing to selection of the physically fit for mining work) than in the general population that coal miners do not have the disease. In a few years after the dust has had time to affect the respiratory passages the incidence of tuberculosis apparently increases rapidly.

Haldane (336) believed that the coal miner was free from silicosis because the inert silica dust was carried away by phagocytes stimulated by the coal, but Kettle (10) disagreed with this theory, as indicated by the following statement:

> Coal dust itself is a complex substance and varies in composition, but all coals consist largely of carbon; is carbon therefore antagonistic to the tubercle bacillus? Carleton suggests that "it is conceivable that pulmonary tuberculosis might favorably respond to a carefully graded inhalation of coal or soot particles", but I should imagine that the failure of this form of therapy is being demonstrated daily among the consumptives of our great cities. I know of no experimental evidence to support this view, and moreover I have not been able to demonstrate any difference from the normal, in their reaction to the tubercle bacillus, of animals saturated with carbon in attempts to block the reticuloendothelial system.
>
> The demonstration of silicosis among coal miners is of such importance because a whole superstructure of theory has been built upon the assumption that it does not exist. From observations in man and in experimental animals we know that when coal is inhaled into the lung it is picked up by phagocytes. By the migration of these phagocytes much of the dust is removed, either by way of the air passages or by the lymphatics. If the quantity of dust inhaled is great, intake will overcome excretion and the coal will remain in the lung. Much of it is deposited in lymphatic vessels, but from the fact that a miner's sputum is pigmented for a long time after he ceases work it would seem that a good deal still remains in the alveoli. The pigmented lung of the city dweller suggests that the excretion is never perfect, but yet it has been claimed that small quantities of coal may entirely disappear from the lungs of experimental animals by this natural method of cleansing. ***.
>
> I have confined my remarks to coal dust because this is the adulterant dust most often quoted, but I have no reason to believe that other concomitant dusts in industries play any specific part in protecting the individual from the effects of inhaled silica. The experiments which have been accepted in the past as having significance are not capable of giving the answer required. We must have a base-line to work on, and in these experiments the base-line must be the production of characteristic silicosis in animals. In the absence of this we are not justified in claiming experimental knowledge of how silicosis may be modified.

The following statement by Böhme (337) regarding pneumoconiosis and tuberculosis among Ruhr coal miners indicates that these diseases do occur among coal miners:

An examination of hospital cases revealed that of 103 coal miners that had been in the work for 10 years or more 30 percent showed pneumoconiosis roentgenologically, while of 66 stonemasons 70 percent revealed pneumoconiosis, mostly of a severe type. Among stonemasons with pneumoconiosis there was found in most cases a high-grade secondary tuberculosis. Among 95 coal miners in this occupation over 10 years there were 5.3 percent with open tuberculosis, and 2 other cases revealed, clinically and roentgenologically, a fibrotic closed tuberculosis. In all there were 18 percent which had then or previously suffered tertiary pulmonary tuberculosis. Among the stonemasons 12 percent were open, 8 percent definitely active, and 23 percent were or had been in the tertiary class.

Carleton (338) experimented with dusts composed of flint and coal, china clay, feldspar, ground pitcher (earthenware), pure amorphous silica, pure flint, coal, shale, ignited shale, dried earth, and ignited earth. Coal was found to initiate early phagocytic response which led to rapid elimination of much, but not all, of the flint dust simultaneously inhaled. He suggested that possibly coal dust might be beneficial in metalliferous mines. China clay, contrary to expectation, was found a potentially dangerous dust, as also were feldspar and ground earthenware. Inhalation of amorphous silica produced lesions even more severe than inhalation of crystalline silica. Coal dust was eliminated rapidly from the alveoli owing to brisk phagocytic response. Shale dust was comparatively harmless, even when previously ignited. According to Carleton (338), "when the paths of dust elimination are examined the more harmful a dust is to the lungs the less far is it found to be removed from the alveoli and the less complete is its removal."

The incidence of silicosis among coal miners in South Wales employed in driving roads in hard silica rock was reported in 1926. Cummins (339) gives an account of the pathological findings in one of these miners who, after exposure to silica dust for 4 years at machine drills, was employed as a coal miner at the face. Neither during life nor after death were tubercle bacilli found. On chemical analysis the lungs were found to contain a little over 10 percent ash, of which 1.4 percent was silica. Ash from the lungs of an ordinary adult gave only 3.2 percent ash with an inconsiderable amount of silica. Microscopically, the lungs exhibited definite and characteristic fibrosis; in addition, a large accumulation of pigment originating in coal dust was found--so much that the upper parts and surface of the lungs felt and looked like coal. Many dust-bearing macrophage cells were seen in the fibrotic tissue, carrying particles of coal dust. Others had disintegrated, leaving their burden of coal dust behind. Cummins (339) compared the occupational exposure of the patient to that of guinea pigs exposed by Mavrogordato first to fine silica dust and later to fine coal dust. The findings agreed closely with those reported by Cummins. The suggestion is made that the lungs were first damaged in their lymph drainage by the fibrosis and subsequently coal dust became entangled there which would have been eliminated from normal healthy lungs. The result was that coal dust, usually considered a harmless dust, accumulated in the lungs and accentuated the preexisting silicosis enough to cause death.

According to Collis (340), coal trimmers (men working for long periods in semiclosed spaces in the holds of ships) exposed to dust from South Wales coal tend to succumb in excess from bronchitis and pneumonia, but not from phthisis. Clinical observation by X-ray examination disclosed that after years of work the lungs of coal trimmers are not normal and exhibit signs similar to those widely regarded as characteristic of silicotic fibrosis.

That dusts other than silica do not prevent silicosis and tuberculosis when inhaled with silica is indicated by Hague and McBain's (341) summary of results of an examination of 4,000 miners of the Porcupine group of mines in Ontario, Canada. They state:

1. The local incidence of silicosis is low in comparison with the Rand of South Africa.

2. The pulmonary condition, as roentgenographed, presents here a picture with contrastingly softer shadows than those from South Africa.

3. "The condition is of much less erious nature and would seem to be caused by rock dust (a) other than silica, (b) containing a small percentage of siliceous dust mixed with that from silicates and other accessory minerals" (C.M. Omerod).

4. Tuberculosis is the predominating serious factor but does not exist to nearly the same extent or virulence as that of South Africa.

A summary in the Colliery Guardian in 1931 of results of investigations by Cummins (342) contains some interesting statements on the value of coal dust in the prevention of silicosis and the treatment of tuberculosis.

A point which comes out clearly from these investigations is that the anthracosis of coal miners is a dual condition in which the retention of coal dust in the lungs is associated with and, in all probability, due to, a state of diffuse or nodular lung fibrosis and lymph blockage indistinguishable from that found in the silicosis of gold miners on the Rand and of those engaged in the "refractories" industries in this and other countries. In the coal miners' lungs the extent of the fibrosis and lymph blockage, the percentage of silica in the lung ash, the number of doubly refractile particles visible in the sections, and the degree of clinical pulmonary disease recorded prior to death are all found to vary directly with the amount of exposure of the individual to silica-containing dust, being greatest in those with an industrial history of work in "hard headings" or as "repairers", although often quite marked in coal miners with no history of work other than at the coal face. The author declares that, in a large proportion of old coal miners of other categories less intimately in contact with stone dust, there is radiological, pathological, and chemical evidence of a condition indistinguishable from pulmonary silicosis. One characteristic feature of silicosis, however, is absent in the case of coal miners--the increased liability to tuberculosis. In fact, there is much reason to think that coal miners, far from being specially liable are, on the contrary, exceptionally resistant to pulmonary phthisis. The

writer's observations into the anthracosis of coal miners suffice to convince him that the simultaneous inhalation of silica dust and coal dust over long periods leads to a blocking up of lymph drainage by silicosis and a resulting retention of the coal dust in the lungs rather than to any increased elimination of one dust with or through the other.

The writer has been able to prove beyond any question that the finely powdered dust of anthracite coal is capable of adsorbing a large proportion of the active principle from old tuberculin diluted with normal saline solution. It is not unreasonable to assume that the presence of large quantities of carbon particles in the immediate vicinity of tuberculous foci might, by adsorbing the products of the growth and destruction of tubercle bacilli, go far to prevent or diminish the inflammatory phenomena which constitute tuberculous disease. Whether the collection of carbon particles which have accumulated in the tissues and been bathed in the tissue juices retain their power of adsorbing tubercle protein is a matter for further investigation, but the probability that they can do so is emphasized by the fact that negative sputa are commoner in clinically tuberculous coal miners than in clinically tuberculous adult males of other occupations in the same district and over the same period. If the relative exemption of coal miners from tuberculosis be admitted, and it can hardly be denied, then this fact must be taken into consideration along with the further fact, newly established, that a large number of coal miners develop pulmonary silicosis in the course of years spent in the industry. It would be rash to suggest that this condition of silicosis in coal miners is free from risk. What tuberculosis is to the gold miner, "bronchitis", perhaps, is to the coal miner, and the high mortality from this latter cause in old colliers is in all probability closely associated with a life of exposure not only to coal dust but to stone dust as well. But the word "silicosis" has come to imply a marked and formidable liability to tuberculosis and is thus accepted in regard to "compensation" in "refractories" industries in the gold-mining industry in South Africa. It is important to dissociate this implication from the word "silicosis" when it is applied to coal miners.

In a later article Cummins (343) asks why silicosis, which is so often the herald of phthisis in the gold miner, does not have the same sinister association in the collier:

Is it a question of some antiseptic action of the coal dust exercised in the lung tissues?

Wainwright and Nichols (1905) were unable to demonstrate any such antiseptic action, although their experiences led them to postulate a "real protective influence" of coal dust in the lungs against tuberculosis. Corper, Starry, and Lurie (1924) failed to discover any antiseptic action of coal dust in the inhibition of the growth of tubercle bacilli in culture but, like the former authors, they, too, found that the presence of coal dust in the lungs of their experimental animals had a definite protective effect against tuberculosis.

It is evident that coal dust has this protective power to a considerable degree and that it does not depend upon any antiseptic action.

The writer has recently (1931) suggested that its antituberculous properties may depend upon its well-known power as an adsorptive agent.

Tubercle bacilli act upon the tissues through the toxic products set free in their growth and disintegration. These toxic products cannot be appreciably different from those of tuberculin. ***.

It must not be supposed, however, that the presence of accumulated coal dust in the lungs is an unmixed blessing. On the contrary it may have very disagreeable or even dangerous results. While it seems to have a definitely beneficial effect in lessening the liability to the extension of tuberculous lesions it may, by its mere accumulation, come to occupy large areas of lung tissue to an extent which leads not only to fibrosis and devascularization, but sometimes to colliquative changes and even cavity formation. With these changes there is brought about, to a gradually increasing extent, a state of lung emphysema accompanied by structural deterioration of alveolar tissue, bronchioles, and even bronchi which involves serious interference with the function of respiration.

Most old coal miners are dyspneic. Although many of them work on to a great age, they are, as a rule, "short of breath" and suffer from copious sputum, cough, and sometimes asthmatic trouble.

While the collier is fortunate in having a relatively low death rate from tuberculosis, his death rate from "bronchitis" is very high. Whether the word "bronchitis" is well chosen to describe the dyspneic state in which old coal miners so commonly die is open to question; and it is a question, too, whether they merely die dyspneic or die from dyspnea. Certain it is that the effects of stone dust and coal dust combined tend, after a life spent in the industry, to produce a stage in which the breathing efficiency of the lungs is seriously compromised. ***.

The fact that the apex of the curve of "bronchitis" mortality in coal miners occurs so late in life shows that the state of lung injury does, however, involve marked respiratory distress and considerable loss of health. This pneumonoconiosis of coal miners is at least a contributory cause in many of the deaths attributed to "bronchitis" and it appears, in itself, to lead to fatal issue in some cases. The attitude of complacency commonly assumed toward the risks run by coal miners from exposure to the mixed dusts of the coal mines is obviously unjustifiable.

Coal dust has been used in the treatment of pulmonary tuberculosis. Glaser (344) administered intravenously 3 cc of a coal-dust preparation, repeating the injection after an interval of 10 days; only 3 injections were given. After each injection the patient was kept in bed for 3 days and the temperature taken every 2 hours. The injections caused pleuritic irritation in one patient and bloody expectoration in another. In one instance the treatment was followed by rapid subsidence of fever; usually the subfebrile temperature persisted

or even developed afterward. The sedimentation speed of the erythrocytes sometimes was reduced or remained unchanged; the general condition improved. The injections proved most efficient in patients with catarrhal lesions, but the effect was transitory. Remarkable improvement was observed in a case of ulcerous productiveocirrhotic tuberculosis after two injections. Glaser points out that the reaction caused by the intravenous injections was different from that caused by inhalation of carbon dust by miners.

Böhme (15) arranged dusts according to harmfulness in the following descending order: Steel-grinding dust, coarse pottery dust, fine pottery dust, coal dust, and soot. He considers the last two probably less harmful than grindstone and pottery dust but states that animals exposed thereto when compared with controls undoubtedly showed that coal dust and soot favored tuberculosis--"an observation of importance in the face of many statements to the contrary, which are mostly based on insufficient material."

In 1934 Fowweather (345) stated that, in general, the dusts in some industries are more potent as silicosis producers than those of other industries; the nature of the inhaled silica has something to do with the onset and development of the disease; possibly, too, accompanying nonsiliceous dusts may exert a modifying effect on the action of the siliceous material inhaled. In his opinion some modifying effect of coal dust, for example, may account for the difference observed between the silicosis of coal miners and that of workers in industries in which coal dust is absent.

Cooke (346) summarizes briefly the trend of thought regarding coal dust:

> A century ago the dangers of inhaling coal dust were accepted; at a later period, associated with a discovered low tuberculosis rate, they were discountenanced; today the dyspneic coal miner with his constant cough, associated chronic bronchitis and emphysema, black lung, resistant and airless parts, with or without pleural effusion or abscesses, and with an abnormally high silica content, is again becoming of serious concern. Although it is probable that the work of Cummins and Weatherall explains the immunity to tuberculosis on the basis that coal dust absorbs the active principle of tuberculin, the other gross pathology--bronchitis, emphysema, and fibrosis--must not be forgotten.
>
> Oliver (1909), Collis (1915), Tattersall (1926), and others have also proved beyond reasonable doubt that there is a serious impairment of lymph drainage in the lungs of coal miners by the action of silica.

Cooke (346) describes a case history, with autopsy, of typical "silicoanthracosis" in a soft-coal miner who had no other employment throughout a long life and whose lungs showed extensive fibrosis, occasional fibrous whorls, emphysema, carbonaceous deposits, and masses of golden-yellow pigment, as well as black angular particles measuring 10 to 80 microns in length. In many respects the curious bodies were those considered typical of asbestosis only, although the miner in question had not been exposed to strata containing iron ore or large amounts of silica. Cooke therefore questioned the constancy of the peculiar bodies in asbestosis. He considers that this case lends strong

support to the theory that anthracosis is primarily a silicosis and that it occurs not only in hard-coal miners but also in workers in soft coals.

Calcium dust.- Authorities have considered calcium dusts the least harmful of the inorganic mineral dusts; in fact, some believe that certain calcium dusts play an important role in hindering the development of tuberculosis or in arresting its progress, basing their view on the physical and chemical qualities of the dusts, on clinical reports, statistical data, and brief animal experimentation. The following review of the literature on this subject is taken from an article by Iszard (347) on Calcium and Tuberculosis, published in 1925.

In discussing the question of mineral dusts in the lime and cement industries Hoffman (348) showed by citing investigations, quoting authorities, and comparing statistical data that "mineral dusts composed of calcium salts are the least injurious of inorganic mineral dusts." In a review of Hoffman's paper the Monthly Labor Review (349) stated that "the evidence is also conclusive that workers exposed to marble or limestone dust suffer a decidedly lesser liability to pulmonary tuberculosis than those exposed to granite or sandstone dust with a high silica content."

According to Koelsch (350), Summerfield claimed that of 20 workers occupied up to 30 years in a Berlin gypsum factory none showed signs of tuberculosis.

Rössle (351) claimed that mortality from tuberculosis among workers in lime and cement industries was favorable, and when tuberculosis is found among these workers it always develops slowly.

According to Nieszytka (352), Hirt claimed that chalk, gypsum, and cement were the least harmful dusts for the respiratory organs. To show the value of calcium therapy in pulmonary tuberculosis, Maendl (353) quoted Fissak, who stated that of 40,824 deaths only 17 (0.041 percent) occurred among calcium and gypsum burners; the German gypsum union claimed that of 400 workers employed for 17 years in a gypsum factory not one had died of tuberculosis. For this reason Maendl thought that methodical gypsum-dust inhalation treatments should be given tuberculous patients.

Reckzeh (354) cited the case of a worker suffering from pulmonary tuberculosis who, on changing his employment to lime-burning, found after several months that his condition had improved. Investigations of several lime factories resulted in negative tuberculosis reports. According to this investigation (354), Halter attributed the beneficial action of calcium to its dehydrating action on air and Weber, Hirsch, and Hunter claimed that the dryness of air containing calcium has a drying action on the pus. Reckzeh (354) treated 8 tuberculous patients with lime; he placed them in a room for 5 minutes a day and created dust by beating bags containing lime. No positive results were obtained.

According to Nicholson (355), all dusts are not equally harmful; coal possibly is beneficial, lime neutral, and silica injurious. Thompson (356)

stated that "upon the whole, in proportion to the quantity of dust inhaled, cement dust, like coal dust, produces less damage to the respiratory system than might be supposed--less than the harder, sharper flint or glass dust, although chronic bronchitis, asthma, and pneumonoconiosis may result from it."

As a result of personal investigations among limeworkers, Selkirk (357) concluded that they showed exceptional health and cited Renon as saying that when a limestoneworks opened up in a particular place there was a decrease in tuberculosis among the people of the neighborhood. Selkirk (357) suggested that individuals predisposed to tuberculosis should work in cement and lime and that perhaps a limeworks should be started as a tuberculosis cure.

As a result of investigation of the dust problem in some portland-cement plants, Tucker (358) claimed that there was "no evidence of injurious effects from cement dust on employees engaged in its manufacture." This conclusion was based on the examination of 956 employees of 1 plant and of the men employed in the dusty departments of 4 other mills, as well as on hospital records and guinea-pig experimentation.

In an article on lime and tuberculosis Rockwood (359) likewise suggests the possibility of lime dusts having a beneficial effect on pulmonary tuberculosis and causing an inhibition of the tuberculous process. He based this belief on an intensive and interesting series of reports from managers of plants engaged in the manufacture of calcium products.

Tweddell (360) visited 22 plants and found no cases of tuberculosis; a number of gypsum manufacturers (361) make similar reports.

Nagai (362) made experiments with guinea pigs, exposing one series to lime dust alone and another series to lime dust containing tubercle bacilli. These dusts were kept in suspension by mechanical agitation. The results showed that lime dust alone had no detrimental effect. When lime dust was superimposed upon a tuberculous involvement or when the dust and bacilli were administered simultaneously the dust had no demonstrable beneficial action.

Cesa-Bianchi (363) conducted a series of experiments in which he dusted guinea pigs with chalk, coal, Thomas slag, gypsum, cement, and mother-of-pearl to study the effect on their lungs. He dusted other animals with the same dusts and superimposed a human strain of the tubercle bacillus; the amount used produced little or no alteration in normal animals. The dusts alone caused no marked alterations of the air passages, particularly no alteration of the lining parenchyma. When the tubercle bacillus was superimposed a marked mediastinal involvement and great swellings of the peribronchial lymph nodes were observed. The author said that all dusts produced similar results except chalk and gypsum, leaving the reader in doubt as to whether he considered these beneficial.

Gardner and Dworski (364) found that the greater portion of inhaled marble dust is soluble in the lung tissues and that the inhalation of this dust during the progress of a preexisting tuberculosis will be followed by the calcification of a certain number of the pulmonary and tracheobronchial lymph-node tubercles. The insoluble siliceous matter causes a small amount of silicosis after prolonged exposure and delays the resolution process.

Iszard (347) summarizes the literature on calcium in the treatment of tuberculosis as follows:

> The statistical data of the United States show that tuberculosis mortality is higher for all calcium-dust industries than for the population as a whole. The percentage, however, is markedly lower than for those industries involving exposure to dust of high silica content. Furthermore, exposure to calcium dust appears to retard the development of the tuberculous process since in the calcium industries the tuberculosis mortality peaks are reached much later in the age scale than in the other dusty trades.
>
> Foreign statistical data rather give one the impression that the calcium industries are beneficial, especially the lime and chalk industries.
>
> Clinical and industrial reports point to either a harmless or a beneficial action of the calcium dusts. The reports from those who have employed calcium dusts in the treatment of tuberculosis vary as to their value. Those employing calcium oxide, with the exception of the French workers, claim that it is of no benefit, while those using calcium sulphate feel that it is helpful in the early stages. The ineffectiveness of the former can be attributed to the caustic action of this dust.
>
> Animal experiments point rather to the fact that calcium dusts act as mild irritants and though playing no important role in the development of tuberculosis, do not arrest its development.

From original experiments, Iszard concluded:

> Calcium hydrate dust is not harmful to the lungs of rabbits. It apparently acts as a mild stimulant, causing the migration of macrophages which remove traces of silica present in the calcium dust. The harmlessness of calcium hydrate dust may be attributed both to its physical and to its chemical nature. The roundness of its particles prevents them from doing marked injury, and their tendency to coalesce prevents many from gaining access to the finer bronchioles. Moreover, the fact that it is soluble in the body fluids permits of its partial removal by way of the blood stream.
>
> When inoculation with tubercle bacilli follows a period of lime-dust inhalation there seems to be a very slight retardation in the development of tuberculous lesions, which nevertheless are indistinguishable from the customary lesions of this infection in rabbits.
>
> When the lime-dusting occurs after the inoculation with tubercle bacilli there is a more distinct retardation of the tuberculous development explainable possibly on the ground that the lime causes an overproduction of macrophages which render inert the tubercle bacilli. Since the lime is soluble in the body fluids there is no noticeable accumulation of foreign mineral matter.

As dissolved calcium is in the blood stream always as bicarbonate and phosphate, the excess, introduced by such experiments as have been detailed, must be deposited in those organs normally characterized by a high calcium content, such as the bones, kidneys, and lungs. In a tuberculous condition, where we have a calcium demineralization, any increase in calcium would tend to balance the existing deficiency and permit of an approach to normal.

Koelsch and Kaestle (365) found that the mortality rate for cementfactory workers did not differ from that for the local population of the same ages but rather remained considerably under the average for the district; the tuberculosis mortality rate in particular was within 10 years under the average for the whole Bavarian population.

In six autopsies of workers in the cement industry Pesenti (77) found sclerosis localized at a few points in the lungs. He believes that the nodular, bronchopulmonary sclerosis follows a slow evolution and provides few subjective symptoms. He noted dyspnea, loss of weight, night sweats, pleximetric and stethoscopic phenomena, and sputum similar to that of tuberculosis in a person in whom tuberculosis was not discovered either macroscopically or microscopically at autopsy; it was a case of multiple nodular sclerosis of the lungs. Pesenti (77) believes that inhaled cement dust neither produces tuberculosis nor favors its evolution but states that this is merely a hypothesis, Loriga (77) considers these observations highly interesting because they present a picture of the various forms of pneumoconiosis without tuberculosis

From a clinical and statistical study Rota and Finzi (77) found that workers in cement and lime have no higher morbidity and mortality rates than other workers, although they are subject more frequently to respiratory diseases and often die at an early age. They state that there is no truth in the belief that limekiln workers enjoy a certain immunity from tuberculosis.

According to Russell (366), cement workers of a group that showed positive signs of arrested tuberculosis were able to work in the dusty atmosphere without any apparent harm to their old tuberculous lesions. He states:

> The amount of calcium in relation to silica or other constituents of inhaled dust appears to be of importance in the incidence and development of industrial tuberculosis. Two facts in this connection stand out prominently in the study: First, no new cases of tuberculosis were found to have appeared as the result of exposure to cement dust; and, second, the cases which had unmistakable evidence of arrested tuberculosis exhibited no tendency to reactivation of the disease. We are led to believe that exposure to dust generated in the manufacture of portland cement is not provocative of tuberculosis, nor is it a factor in reactivation of arrested disease.

Chemical analysis showed that the cement contained about 62 percent of lime and 22 percent of silica. Petrographic analysis showed that the proportion of free silica (quartz) ranged from 6.5 percent in the crusher houses, raw mill, and stone house to about 1 percent in the finished cement. In contrast to the effects mentioned in connection with tuberculosis the frequency of

disability on account of respiratory diseases among cement workers was twice as great as the average respiratory rate among employees of 11 manufacturing plants in relatively nondusty industries. The highest rate for all respiratory disease in any of these establishments was 30 percent below the rate of cement workers.

During 1934 and 1935 much attention has been directed to suits filed in the courts of various parts of the United States, alleging harm to health from breathing dusts; in several hundred of these the complainants have alleged that they have been wholly or partly incapacitated by breathing dust composed chiefly of limestone. Several rather heavy judgments have been awarded in these suits (which generally, however, were appealed), some of them in connection with breathing dust containing less than 3 percent (and in some cases less then 1 percent) silica; the main constituent was limestone.

Confidential data in the possession of the authors indicate that some coal-mining companies using pulverized limestone dust for rock-dusting to prevent coal-dust explosions have had difficulty with employees engaged in the rock-dusting work who have complained that the breathing of the accompanying large amount of the fine rock dust (90 percent or more limestone and usually less than 5 percent silica) has caused serious illness; in some cases the employee has been taken off the work and in other cases he has been provided with an up-to-date dust respirator.

Clay dust.- In 1919 Landis (367) stated that he knew of several potters who became tuberculous, had the disease arrested, and returned to their former work. In each case after a number of years had elapsed the patient was well in spite of being exposed to the same conditions as existed before his illness.

As mentioned above with regard to coal dust, apparently the fact that workers in certain dusty industries do not succumb to tuberculosis at as early an age as the tuberculous victims who have not been exposed to industrial dust is the basis for the belief that certain dusts exert a "protective" action against the development of the disease. However, the force of this argument for the "protective" value of such dusts seems to be nullified by mortality figures for older workers quoted by its adherents. This point is well-illustrated by the following quotation from a report by Landis (367) on clay dust:

> It has long been recognized that the age period at which potters succumb to tuberculosis is far beyond the average, and in addition the disease seems to be much less severe than the same amount of damage produced in other classes of patients. Most of the available statistics on the subject support this view. Thus the English mortality statistics for the 3 years ending 1902 state that the mortality of potters, between the ages of 20 and 35 years, falls below that of occupied and retired males generally. At every other period, however, it shows an excess which amounts to no less than 74 percent at ages 45 to 55 years and to 66 percent at ages 55 to 65 years. The principal excess falls under the head of respiratory diseases.

The following table shows the proportionate mortality from consumption among potters, compared with that of males in the registration area in the United States.

Age at death	Percent of deaths due to tuberculosis among--	
	Potters	Males in registration area, 1900-1906
15 to 24 years	23.9	27.8
25 to 34 years	52.9	31.3
35 to 44 years	44.0	23.6
45 to 54 years	28.2	15.0
55 to 64 years	19.4	8.1
65 years or over	19.4	2.7

My own belief is that the higher incidence of tuberculosis among those exposed to inorganic dust is due to the fact that the dust acts as a convenient carrier of tubercle bacilli. In other words, it is not the preliminary injury which the dust is responsible for that predisposes the individual to tuberculosis, but the readiness with which tubercle bacilli may be carried into the respiratory tract by a dust-laden atmosphere.

In 1925 Landis (368) stated in regard to potters that "the damaging effects of the inorganic dust become more and more noticeable after the age 40. There are relatively few workers remaining at the trade beyond the age of 60. They become incapacitated as a result either of pneumoconiosis or of a superimposed tuberculous infection."

In 1926 Heffernan (369) called attention to the relative immunity of Derbyshire silica brickmakers from silicosis, which he said was due not to the shape of the silica particles but to the fact that the material used was not pure silica but a mixture of about 84 percent silica and about 16 percent clay and earth with some organic matter; the presence of these latter materials appeared in some way to inhibit the action of the silica dust. In support of this contention he quoted the following conclusion reached by Smith and Collis (370):

> This inquiry has revealed an unsuspected fact, viz--that the influence of silica dust in favoring tuberculous infection is modified when the silica is mixed with certain clays. Ganister or other stones containing a high percentage of free silica are mixed with clay sufficient for binding purposes in the manufacture of certain refractory bricks and other articles; and stone is added in varying proportions to fire clay to increase its refractory properties or to modify or reduce the amount of shrinkage when subjected to high temperatures. During this inquiry no history has been obtained, up to the present, either from workers or occupiers that a high mortality from phthisis is experienced by those employed in the manufacture of such articles containing clay as an admixture.

Heffernan (369) states that exactly how this protection comes about "is an unsolved but very interesting problem, the solution of which may completely alter our present ideas regarding the prevention of silicosis."

The Report of the Safety in Mines Research Board of Great Britain (371) contained the following very striking deductions from the work done at the physiological laboratory of St. Bartholomew's Hospital under the direction of Haldane:

> While many dusts cause pulmonary fibrosis, silica is the dust which most predisposes to tuberculosis. This is doubtless due to its influence in forming a medium suitable not only for the survival, but for the proliferation of the tubercle bacillus in the lung (Kettle). The harmful effect of soluble silica may be neutralized by simultaneous administration of basic dusts, such as aluminium hydroxide or magnesium carbonate, though the latter are themselves harmful when inhaled alone. It is suggested that their respective solutes combine to form silicate. Monosilicates do not appear to have any harmful effect on the lung.
>
> Heavy inhalations of any dust are liable to cause pulmonary damage. The intensity of the initial pulmonary reaction to a dust is very generally in inverse ratio to the degree of eventual damage caused by the dust.
>
> The following dusts produce a fibrosis in the guinea-pig's lung and are, therefore, to be classed as dusts whose inhalation in industry would be attended by risks of pneumoconiosis. The most deadly of all dusts examined was precipitated silica. Less dangerous, but all producing fibrosis, were the following arranged in order of decreasing toxicity: Flint, slate, aluminum hydroxide, precipitated chalk, magnesium carbonate, and carborundum. In the concentrations used in the experiments calspar and emery were borderline dusts, indicating that their inhalations in any considerable quantity would cause fibrosis. Wood charcoal inhaled in large amount produces a slight fibrosis, and must therefore be considered potentially dangerous, as also must very fine coal dust when inhaled in very large amounts.
>
> Hematite, however, initiated a brisk proliferation of the alveolar epithelium on its entry into the lung.
>
> The experiments have shown that pulmonary fibrosis may be caused by dusts which in human experience are innocent in that they do not appear to predispose to tuberculosis.

The following reports of investigations on the effects of inhaling a dust containing aluminum and one containing hematite are interesting in connection with the above statements regarding neutralization of harmful effect of soluble silica by certain other dusts.

In 1932 Gudjonsson (372) reported the results of an examination of 78 workers who had been employed in a plant in Denmark for over 2 years in crushing and grading a mineral composed mainly of aluminum sodium fluoride, known in Greenland as "cryolite." He stated that half the workers on X-ray examination

showed a condition, in different stages, similar to that found in cases of silicosis when originated by silica dust. He summarizes his results as follows:

1. On examination of the local conditions in a factory where cryolite is crushed it was found that most of the working processes were accompanied by the production of mineral dust, cryolite, containing only 3 percent quartz and that in some parts of the plant the dust production was very marked.

2. An examination of 78 workers, who had been occupied in this place over 2 years revealed various degrees of silicosis--up to second stage--in 40.

3. The development of silicosis appears to be in direct relation to the time the workers affected have been occupied in this place, and not in direct relation to their age.

4. The total sick rate during the last years has increased among the workers with silicosis. This applies especially to diseases of the lungs--in this group of diseases the total sick rate is more than 3 times as high among silicotic workers as among nonsilicotic.

5. Signs of pulmonary tuberculosis were demonstrated in four of the workers examined, but they were not confined to silicotic workers.

In 1926 Cronin (371) reported on an examination of 100 drillers in iron mines; the main geologic formation met by the drillers was hematite and limestone. The medical history of these drillers was particularly clear; some had been drilling for 30 years without a day's absence from illness. Among the 100 subjectsthe only illnesses contracted during the period spent in drilling were a few cases of mild influenza, a case each of lumbago, neuritis, rheumatism, and 2 cases of pleurisy; 27 percent of the men made no complaint whatsoever. Nevertheless a large proportion of the men definitely admitted certain symptoms arising from inhalation of the dust. Furthermore, these symptoms were constant in different districts, a fact that eliminated the possibility of collusion among the men and strengthened the evidence considerably. Cronin (373) divides the symptoms experienced into immediate or transitory and permanent. The immediate symptoms were irritation of the nose and throat during drilling, a "clogged-up" feeling, and a tendency to hawk up the dust for a short time after coming out of the mine, but there was no permanent cough. The most constant permanent symptom was shortness of breath, often admitted by young men; this was not experienced at rest but only on exertion ranging in severity from climbing a hill in severe cases to the use of a drill in mild cases. Shortness of breath on exertion was much in excess of the normal and could not be explained by symptoms of cardiac insufficiency or correlated with symptoms of other lung diseases such as asthma, bronchitis, or large-lunged emphysema. According to Cronin (373):

The physical examination of these men revealed certain striking facts, particularly outstanding when contrasted first with the physical condition of the men who had drilled in South Africa, and then with the condition of the controls, i.e., men who had been working underground in the hematite mines for many years, but who had not been exposed to the dust.

Sixty-four of the 100 drillers examined could be classed clinically as possessing normal chests or conversely as affording at least no distinct clinical evidence of pathologic change in the lungs. On the other hand, while 6 percent were doubtful, 30 percent showed very well-defined and constant features, which were, in the order of their importance:

1. Loss of ability to expand the chest fully on forced inspiration. In producing this expansion the subjects were able to use, and did use markedly, the accessory muscles of respiration.

2. An abnormal accentuation of the supraclavicular and the infra-clavicular hollows, usually corresponding with a slight flattening of the chest in these regions.

3. While there was an absence of variation in the note on opposite sides, i.e., evidence of patches of massive fibrosis or of pleural involvement was constantly lacking, the note elicited on percussion was in many cases generally duller and less resonant than normal.

4. In certain cases there was found a well-marked deviation from the normal breath sounds, which assumed an almost puerile or at least broncho-vesicular character. In only one case were adventitious sounds in the nature of rales and ronchi obtained, and this was in a case of chronic bronchitis contracted 10 years before the man had commenced to work underground. There was no evidence of any pleural involvement on auscultation, except in one case where over a limited area a doubtful crepitation might have existed.

Cronin (373) concluded from his investigation that--

1. The inhalation of hematite dust produces certain tissue changes in the lungs of iron-ore drillers.

2. Such changes are not localized but are generalized or diffuse throughout both lungs, although the apices are perhaps more affected than the bases.

3. These tissue changes do not give rise to the pulmonary diseases, i.e., asthma, bronchitis, pneumonia, and phthisis, which commonly result from dust inhalation, but produce the independent and striking sympton complex which has already been described.

These deductions are given additional weight by comparison with pathologic research. Clinically the results of hematite inhalation do not resemble those of silica inhalation but present a unique picture, while the

sections obtained by Sir Kenneth Goodby from the lungs of an iron stone miner clearly indicated not only the presence of a considerable amount of iron as shown by differential staining but also a fibrosis which was essentially general throughout the lungs, finer and quite opposed to the nodular whorled masses of the silicotic lung.

Among the thousands of lawsuits that have been instituted in the courts of the United States in the last few years in connection with dust disease scores (possibly hundreds) of them are by workers in iron-ore mines where the main component of the material handled is hematite and the silica content is usually less than 20 percent and often less than 10 percent. Many of these cases have been diagnosed as silicosis, and in some instances tuberculosis is said to have intervened; several of these suits have been settled out of court.

Alkali Method

Another method tried in the treatment of silicosis is the use of alkalies like sodium bicarbonate. The treatment is based on the observation of the investigators that when silica in solution or as powdered quartz enters the blood stream from the digestive tract it is eliminated quickly by the kidneys; the same is true when solutions of silica are injected directly into the veins, as the body apparently has a very efficient mechanism for disposing of silica after it has entered the blood stream in soluble form. Tests on miners and on healthy laboratory workers who had been exposed to a large amount of quartz dust for a day showed that they were actually eliminating more than the normal amount of silica; evidently the mildly alkaline tissue fluid in the lungs was dissolving some of the silica inhaled and as a result it was entering the blood stream and being eliminated. In the hope of accelerating this natural effort of the body to rid the lungs of disease-producing silica King and Dolan (374) gave alkali medicine, but the results were inconclusive.

In this connection it is interesting to note the results of a study by the United States Public Health Service (375) of the urinary excretion of silica by persons exposed to silica dust. One hundred and twenty-three anthracite workers, 20 of whom had been out of the industry an average of 7 years, were examined for urinary silica by the method of King and Dolan. The amounts of silica found in the urine ranged from 0.6 to 11.7 and averaged 2.5 mg per 100 cc. Normal individuals were found to be excreting only an average of 1.0 mg per 100 cc. A close correlation was found between the silica-dust exposure of these men for a specified number of years and the amount of urinary silica. A study of former anthracite workers showed that even after a lapse of several years away from any silica-dust exposure they were excreting an increased amount of silica.

The data cited above emphasize the divergence of opinion (and even difference in experimental results) of various investigators regarding the harmfulness of certain so-called "protective" dusts and their efficacy in preventing silicosis and tuberculosis when mixed with dusts definitely agreed upon as harmful or their harmlessness when breathed alone.

Section 5. - General Recommendations for Control of Dust Diseases in Industry

Although referring to general industrial diseases, the following recommendations from a report by Bloomfield and Johnson (376) who at the request of health officials investigated conditions in an industrial area in the United States, will serve as a summary of the control of dust diseases in industrial work outlined in this chapter.

The practice of industrial hygiene (control of occupational diseases) falls largely within the province of two types of workers, the physician and the engineer. It is within the sphere of the physician to diagnose occupational diseases and primarily to recognize the existence of those diseases due to the factory environment. Based on the findings of the physician, the engineer is in a position to learn where control measures should be initiated. The engineer's work consists of studying the local plant conditions which have been shown to be detrimental to health and evaluating the various methods which may be designed for controlling the hazards. It is impossible to tell by a mere inspection of a workroom whether toxic materials are present in the air in such quantities as to constitute a hazard and whether the protection afforded is adequate. Precise quantitative measurements are needed. Once these measurements have been made, the engineer is able to determine definitely the extent of the hazard and the necessary remedial measures.

In order to carry out a constructive program of industrial hygiene the minimum requirements are:

(A) A physician thoroughly trained in public-health procedure and having a comprehensive knowledge of the effects upon health of the various materials and processes used in industry; in other words, one trained in industrial hygiene.

(B) An engineer who is also trained in industrial hygiene and who is familiar with industrial processes. He should know the following subjects from both a theoretical and practical viewpoint:

1. Microscopy.
2. Gas chemistry.
3. Mechanics of ventilation.
4. Physiology of ventilation.
5. Industrial sanitation.
6. Illumination.
7. Industrial-hygiene survey methods.

(C) A completely equipped laboratory for carrying on studies in industry. With such personnel and facilities, the following program could be inaugurated:

1. Reporting of all occupational diseases to the division carrying on industrial-hygiene work. This will definitely establish where and to what extent certain occupational diseases are occurring and suggest corrective measures.

2. In order to acquaint industry, the medical profession, and others interested in such a program, it may be necessary that the personnel carry on an educational compaign, designed to instruct and interest the various groups involved, as to the importance of the problem, in an effort to further the program. It has been the experience of health departments that the best way to conduct work in industrial hygiene is to cooperate fully with industry, conducting studies in plants, as a rule, only upon request of industry. At the completion of such studies a confidential report on the results should be presented to the plant officials, with recommendations for the improvement of conditions, if such information is necessary and available. All this should be made very clear to the individuals concerned, in order to obtain the cooperation and aid necessary for such work.

3. Studies of the workroom environment and the health of workers by the industrial-hygiene personnel as outlined in 2.

4. In order to carry on this work with the minimum amount of friction and in a spirit of cooperation, it may be necessary to provide a law or regulation which specifically states that the results of any investigation made by the health department can in no way be used in litigation, either by the employer or by the employee. The need for such a ruling is obvious if the interests of all concerned are to be served justly. Attention is called to the act under which the Bureau of Occupational Diseases of the Connecticut State Department of Health functions, as well as to the excellent work this Bureau is accomplishing in the control of occupational diseases in that State.

The additional cost for maintaining industrial-hygiene personnel of the number and type given would not exceed $10,000 a year, or slightly more than 1 cent per capita in the present case. When one realizes the fact that 1 case of silicosis often costs more than the $10,000 needed for a preventive program of the type outlined, the financial phase of the problem should certainly not preclude the establishment of such a vital adjunct of a health department in a large industrial center.

In closing, it is well to emphasize one important point--namely, that occupational diseases are in a large measure preventable, and the degree of prevention exercised by a community will be reflected in the general health status of that community.

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August 1935

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

LIST OF STANDARD STARTERS AVAILABLE TO PROSPECTIVE BUILDERS OF PERMISSIBLE OUTFITS[1]

By H. B. Brunot[2] and M. W. Means[3]

The United States Bureau of Mines under provisions of Schedule 2C[4] issues approvals covering complete operating units such as loading machines, room hoists, and storage-battery locomotives. Certain manufacturers design and build entire machines. Other manufacturers purchase a part or all of the electrical accessories from manufacturers of electrical equipment and make up permissible units by assembling them.

Before the assembler purchases electrical accessories for use in such contemplated units he may require certain information from the accessory manufacturer as to whether the particular accessories are suitable for assembly in his proposed permissible outfit. To aid accessory manufacturers in marketing their product, a provision was incorporated in Schedule 2C whereby tests might be made on individual accessories and reports rendered as to the suitability of a given accessory for use in permissible assemblies.

The section of Schedule 2C which permits this special work reads as follows:

CONDITIONS UNDER WHICH SEPARATE PARTS WILL BE INVESTIGATED AS TO SUITABILITY FOR INCORPORATION ON PERMISSIBLE MACHINES

> Manufacturers having a motor, controller, or other separate electrical units which they wish to offer to a prospective builder of permissible machine may submit such units for inspection and test and obtain a report on the results from the Bureau. (See Inspection and Test Reports, p. 23.)

1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprint from U.S. Bureau of Mines Information Circular 6849."
2 Associate electrical engineer, U.S. Bureau of Mines, electrical section, Pittsburgh Experiment Station, Pittsburgh, Pa.
3 Assistant electrical engineer, U.S. Bureau of Mines, Pittsburgh Experiment Station, Pittsburgh, Pa.
4 U.S. Bureau of Mines, Explosion-Proof Mine Equipment: Schedule 2C, February 1930, 27 pp.

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Application

A letter accompanied by appropriate fees and requesting an investigation into the qualifications of the unit for incorporation in permissible machines, should be addressed to the Director, Bureau of Mines, Washington, D.C.

Inspection and Tests

The procedure followed by the Bureau in making inspections and tests of units to determine their suitability is identical with that followed for parts of permissible equipment as previously outlined in this schedule. The fees, drawings, and other details to be taken care of by the manufacturer are likewise the same for separate units as for parts of complete machines submitted for approval.

Report of Suitability

When a separate unit has passed the required inspections and tests and suitable drawings have been filed with the Bureau a formal letter of notification that the unit has the necessary qualifications will be furnished the manufacturer from the Washington office of the Bureau. This letter will authorize the manufacturer to offer such a separate unit to a builder of permissible machines with the assurance that, unless modified further, inspection and test of the unit will not be required by the Bureau. The use of the Bureau's name on any label or plate attached to the separate unit, or advertising the unit as "approved," will not be sanctioned.

Note: It should be understood that a Bureau of Mines approval covers complete machines only, and therefore approval of machines in which separate units are installed cannot properly be claimed by the assembler or builder without first obtaining formal authorization from the Bureau.

Starters that have been tested and inspected in accordance with the foregoing procedure and found satisfactory or starters that have already been used in permissible assemblies can be offered to prospective customers with the assurance that if furnished in the exact design previously tested they need not be retested to obtain approval of a permissible assembly of which the starter constitutes a part.

A customer, however, often wants a starter slightly different from the one previously tested and inspected by the Bureau. If the change is such as to alter the unoccupied space (internal volume) of the starter, affect the flange joints of the starter or covers, or modify other flame paths a retest will in most instances be deemed necessary. Also a change in material or a modification of the bolt spacing may require a retest.

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The following list of starters has been prepared in order that prospective purchasers may have a ready list of those that have been judged suitable for incorporation in permissible outfits. This list includes only standard starters for general application. A number of the manufacturers listed below are in a position to furnish a large variety of special control for permissible applications without extensive modifications in compartments which have complied with the suitability requirements of the Bureau.

"ACROSS-THE-LINE" D.C. STARTERS

B. P. Tracy Co. Starter

The B. P. Tracy "across-the-line" starter is suitable for starting motors rated up to 5 hp.: 250 or 500 volts D.C. It includes a two-pole manually operated contactor with a magnetic overload relay. As the operating mechanism is not the trip-free type, a fuse is included in the starter. The lead entrances are the stuffing-box type.

Brown-Fayro Co. Switch

The Brown-Fayro Co. across-the-line switch is suitable for starting motors rated up to 5 hp.: 250 or 500 volts D.C. It is a manually operated two-pole, single-throw, knife-blade type with a quick-break mechanism. A magnet coil holds the switch closed against a spring. A thermal relay is used for overload protection. As the operating mechanism is not the trip-free type, a fuse is included in the starter; this fuse also provides the necessary short-circuit protection. The lead entrances are the stuffing-box type.

Crocker-Wheeler Electric Mfg. Co. Switch

The Crocker-Wheeler across-the-line switch is suitable for starting motors rated up to 5 hp.: 250 or 500 volts D.C. It is a two-pole knife-blade type with quick-break mechanism. A fuse is used for overload protection. An interlocked fuse plug is provided to prevent renewal of the fuse with the switch in the closed position. The lead entrances are the stuffing-box type.

Cutler-Hammer, Inc., Starter

The Cutler-Hammer across-the-line starter is suitable for starting motors rated up to 5 hp.: 250 or 500 volts D.C. It includes a two-pole manually operated contactor and a thermal overload. A fuse is provided both because the operating mechanism is not the trip-free type and to give short-circuit protection. The lead entrances are the stuffing-box type.

Flood City Brass & Electric Co. Starter

The Flood City across-the-line starter contains a 250-volt, two-pole, manually operated circuit breaker with trip-free-type operating mechanism. The current rating is up to 50 amperes. Thermal overload and short-circuit protection are provided. The lead entrances are the stuffing-box type.

General Electric Co. Type CR-4850-B1 to B6 Starters

The General Electric Type CR-4850-B1 to B6 across-the-line starters are suitable for starting motors rated up to 5 hp.: 250 or 500 volts D.C. These starters contain a double-pole contactor operated by a start-stop control switch. A thermal relay provides overload protection. A fuse is used for short-circuit protection. The lead entrances are the stuffing-box type.

Goodman Manufacturing Co. Type 21575 Switch

The Goodman Manufacturing Co. across-the-line switch is suitable for starting motors rated up to 1 hp.: 250 or 500 volts D.C. It is a two-pole, single-throw, knife-blade type with auxiliary blades for quick break. A fuse is used for overload protection. An interlocked cover prevents renewal of the fuse with the switch in the closed position. The lead entrance is the insulated-stud type.

South Fork Foundry & Machine Co.
Louder Safety Switch

The Louder safety switch is an across-the-line switch for starting motors rated up to 5 hp.: 250 or 500 volts D.C. It is a two-pole knife-blade type. A fuse provides overload protection. Quick-break action is obtained by springs mounted in conjunction with the operating handle. An interlocked cover prevents renewal of the fuse with the switch in the closed position. The lead entrances are the stuffing-box type.

Ohio Brass Co. Starter

The Ohio Brass Co. across-the-line starter is suitable for starting motors rated up to 1-1/2 hp.: 250 or 500 volts D.C. Magnetic and thermal overload protection are provided. The lead entrances are the stuffing-box type.

Crouse-Hinds Co. Type FLB-GM Condulets

The Crouse-Hinds Co. D.C. across-the-line starter contains a manually operated circuit breaker, 2 poles for 250 volts and 3 poles (2 poles in series on positive line) for 500 volts, with trip-free-type.operating mechanism. The current rating is up to 50 amperes. Thermal overload and short-circuit protection are provided. The case is tapped to receive stuffing box or sealed-type rigid conduit lead-entrance fittings. (The lead-entrance fittings are not supplied with the starter.)

Jeffrey Manufacturing Co. Class 27 Switch

The Jeffrey Manufacturing Co. Class 27 switch has been used as an across-the-line starter for 3- and 5-hp. 250-volt and 3-hp. 500-volt D.C. motors and for a 250-volt motor having an intermittent rating of 7-1/2 hp. It is a two-pole, single-throw, drum-type switch. A fuse is used for overload protection.

An interlocked cover prevents renewal of the fuse with the switch in the closed position. The lead entrances are the stuffing-box type.

Westinghouse Electric & Manufacturing Co. Drum-Type Switch

The Westinghouse drum-type switch is an across-the-line starter for 230-volt D.C. motors rated up to 5 hp. It is built both for reversing and non-reversing service. A fuse is used for overload protection. An interlocked cover is provided to prevent renewal of the fuse with the switch in the closed position. The lead entrances are the stuffing-box type.

Westinghouse Electric & Manufacturing Co. Type "C"
Class 8508 Starter

The Westinghouse type "C" across-the-line starters are suitable for starting motors rated up to 5 hp.: 230 or 500 volts D.C. These starters are the contactor type with push button, thermal overload, and fuse short-circuit protection. The lead entrances are the stuffing-box type.

"ACROSS-THE-LINE" A.C. STARTERS

General Electric Co. Type CR-7850-D1 Starter

The General Electric Type CR-7850-D1 across-the-line starter is suitable for starting motors rated up to 15 hp. at 220 volts or 20 hp.: 440 volts A.C. This starter is the push-button type with a three-pole contactor. A thermal relay provides overload protection. Fuses are used for short-circuit protection. The lead entrances are the stuffing-box type.

Jeffrey Manufacturing Co. Class 26
Switch

The Jeffrey Class 26 across-the-line switch is furnished either with or without a reversing feature. It has fuse overload protection and is suitable for starting motors rated up to 7-1/2 hp.: 220 or 440 volts A.C. An interlocked cover prevents renewal of the fuse with the switch in the closed position. The reverse lever is interlocked with the switch handle to prevent reversing with the switch closed. The lead entrances are the stuffing-box type.

Westinghouse Electric & Manufacturing Co. Class 11200-H-4
11200-A-4 Starters

The Westinghouse Class 11200-H-4 A.C. across-the-line starter is suitable for starting motors rated up to 5 hp.: 220 volts or 7-1/2 hp.: 440 volts; the Class 11200-A-4 is suitable for starting motors rated up to 10 hp.: 220 volts or 20 hp.: 440 volts A.C. These starters are the push-button type with three-pole contactors. Thermal relays provide overload protection. Fuses are used for short-circuit protection. The lead entrances are the stuffing-box type.

Westinghouse Electric & Manufacturing Co.
Class 11200-C-4X Starter

The Westinghouse 11200-C-4X A.C. across-the-line starter is suitable for starting motors rated up to 20 hp.: 220 volts or 40 hp.: 440 volts A.C. This starter is the push-button type with a three-pole contactor. Thermal overload and fuse short-circuit protection are provided. The lead entrances are the stuffing-box type.

Jeffrey Manufacturing Co. Line-Starter

The Jeffrey Manufacturing Co. line-starter for cutting machines is suitable for starting motors rated 50 hp.: 220 or 440 volts A.C. The starter is the push-button (or control-switch) type with a three-pole contactor. Three magnetic relays provide overload and short-circuit protection. The lead entrances are the stuffing-box type.

Crouse-Hinds Co. Type FLB-GM Condulets

The Crouse-Hinds Co. A.C. across-the-line starter contains a manually operated 220- or 440-volt three-pole circuit breaker with trip-free-type operating mechanism. The current rating is up to 50 amperes. Thermal overload and short-circuit protection are provided. The case is tapped to receive stuffing box or sealed-type rigid conduit lead-entrance fittings. (The lead-entrance fittings are not supplied with the starter.)

"1-, 2-, AND 3-STEP" D.C. STARTERS

General Electric Type CR-4850-A-1 Starter

The General Electric Type CR-4850-A-1 starter is a manually operated contactor-type starter with 1 step of resistance, suitable for starting motors rated up to 5 hp.: 250 or 500 volts D.C. The operating mechanism is the trip-free type. Thermal overload and fuse short-circuit protection are provided. The lead entrances are the stuffing-box type.

General Electric Co. Type CR-4850-C-1 Starter

The General Electric Co. Type CR-4850-C-1 starter with 2-step acceleration is suitable for starting motors rated up to 15 hp.: 250 volts or 20 hp.: 500 volts D.C. This starter is the contactor type with push button, thermal overload, and fuse short-circuit protection. The lead entrances are the stuffing-box type.

General Electric Co. Type DJ-157-A Control Group

The General Electric Type DJ-175-A control group is a master drum-switch-operated 1-step contactor starter with a manually operated drum reverse switch suitable for starting motors rated up to 15 hp.: 250 volts D.C. A magnetic relay provides overload and short-circuit protection; an auxiliary thermal relay prevents overheating the resistance. The lead entrances are the stuffing-box type.

Jeffrey Manufacturing Co. Class 26 Starter

The Jeffrey Class 26 starter is manually operated with 1 step of resistance. It is furnished with or without a reversing feature. It has fuse overload protection and is suitable for starting motors rated up to 10 hp.: 250 or 500 volts D.C. An interlocked cover prevents renewal of the fuse with the switch in the closed position. The reverse lever is interlocked with the switch handle and prevents reversal with the switch closed. The lead entrances are the stuffing-box type.

Westinghouse Electric & Manufacturing Co. Class 8518-SM Starters

The Westinghouse Class 8518-SM 1-step starters are suitable for starting motors rated up to 15 hp.; the 2-step starters are suitable for starting motors rated up to 25 hp.: 250 or 500 volts D.C. These starters are the contactor type with push button, thermal overload, and magnetic short-circuit protection. The lead entrances are the stuffing-box type.

Westinghouse Electric & Manufacturing Co. Class 8518-SM Reversing Starters

The Westinghouse Class 8518-SM reversing 1-step starters are suitable for starting motors rated up to 15 hp., and the 2-step starters design are suitable for starting motors rated up to 25 hp.: 250 or 500 volts D.C. These starters are the contactor type with manual drum reversing switch, having auxiliary contacts for the control circuit. Thermal overload and magnetic short-circuit protection are provided. The lead entrances are the stuffing-box type.

Sullivan Machinery Co. Starters

The Sullivan Machinery Co. has 2- and 3-step starters suitable for starting 30-hp. air compressors at 250 or 500 volts D.C. These starters are the contactor type with magnetic overload protection. A two-pole switch with an interlocked fuse plug is incorporated in the design mainly to provide a break in the negative line. One control contains a manual reverse switch with a pilot for operating the starter panel; the other starter is operated by a push-button. The lead entrances are the stuffing-box type.

The company has 1- and 2-step starters suitable for starting 30- and 50-hp. cutting-machine motors at 250 or 500 volts D.C. These starters are the contactor type with push button, magnetic overload, and short-circuit protection. One starter has a manual reverse and another a trip-free-type two-pole circuit breaker with both thermal and magnetic overload. The lead entrances are the stuffing-box type.

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Clark Controller Co. - Joy Manufacturing Co. Starter

The loading-machine starter made by the Clark Controller Co. for the Joy Manufacturing Co. is a 2-step contactor starter suitable for starting 35-hp. motors at 250 or 500 volts D.C. It has lever-operated control switches, magnetic overload and short-circuit protection, and a manual reverse. The lead entrances are the insulated-stud type. This starter is also built with a two-pole switch having an auxiliary control-circuit contact. The switch has a stuffing-box lead entrance for the incoming cable and permits connecting the shunt field before the armature circuit is completed.

I. C. 6850

September 1935

Department of the Interior

United States Bureau of Mines
John W. Finch, Director

INFORMATION CIRCULAR

PETROLEUM REFINERIES, INCLUDING CRACKING PLANTS, IN THE UNITED STATES, JANUARY 1, 1935

BY

G. R. Hopkins and E. W. Cochrane

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PETROLEUM REFINERIES, INCLUDING CRACKING PLANTS, IN THE UNITED STATES,

JANUARY 1, 1935[1]

By G. R. Hopkins[2] and E. W. Cochrane[3]

INTRODUCTORY SUMMARY

Although many small refineries were dismantled in 1934 the total number of plants, including a few under construction, increased from 604 at the beginning of the year to a new high of 638 on January 1, 1935. The capacity also reached a new record, the total of 4,072,400 barrels of crude oil daily being about 45,000 barrels higher than the previous high of January 1, 1932.

The number of refineries increased materially in 1933, following construction in east Texas and the building of many small plants in the Rocky Mountain district and elsewhere. Most of the new plants of 1933 were built to provide an outlet for crude or because the ratio between crude oil and gasoline prices appeared conducive to profits. However, low gasoline prices and increased costs in 1934 dispelled the hopes for profits; many plants were shut down, and some were dismantled. The number of operating plants declined from 454 on January 1, 1934, to 435 on January 1, 1935, but the number of inactive plants increased from 137 to a new high of 196 during the same period. As indicated above, new construction was at a minimum in 1934, and on January 1, 1935, only 7 plants were being built.

Although the trend in number of plants is helpful in providing an insight into general prosperity of the independent refiners the crude-oil capacity furnishes a better index of the growth of the industry. On January 1, 1935 the total daily crude-oil capacity of the completed plants was 4,058,500 barrels, or about 4 percent higher than the total on January 1, 1934. Most of this increase is attributable to east Texas where the completed capacity increased from 128,400 barrels on January 1, 1934 to 179,000 barrels on January 1, 1935. Considerable modernizing was done at the large, established plants but this hardly offset the dismantling of some plants which had been idle for a number of years.

An analysis of the trend of operating capacity for 1934 indicates a steady gain in capacity between March and September, the period of heaviest consumption, with a decided decline in November and December. The weighted average operating capacity for the year was about 3,600,000 barrels, and as daily average crude runs were 2,454,000 barrels the refineries operated at about 68 percent of their capacity in 1934, compared with 67 percent in 1933.

As most of the new plants added to the list in 1934 were skimming plants the preponderance of that type in point of number increased further. The total capacity of the skimming plants increased and that of the complete plants remained virtually unchanged, but because all the larger ones are complete plants the total capacity of that type is still considerably in excess of the total for the skimming plants.

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U.S. Bureau of Mines Information Circular 6850."

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On January 1, 1935, 709 pipe stills were completed or under construction, 10 more than reported a year ago. The total capacity of these pipe stills was 3,024,344 barrels compared with a total of 2,950,414 barrels a year ago. Of the total capacity on January 1, 1935, 2,664,746 barrels (88 percent) was operating on that date. The total capacity of those operating on crude oil was 2,020,880 barrels, leaving 1,608,869 as the total capacity of all the shell stills operating on crude on January 1, 1935.

Although very few of the new refineries were equipped with cracking plants a quiet, but effective campaign of modernization and new construction at the established plants raised the total cracking capacity, as measured by the daily average charge of fresh cracking stock, to a new high of 2,229,269 barrels on January 1, 1935. The proportion of the total cracking capacity which was operating showed a further increase in 1934; in this respect, the crude-oil and cracking capacities showed a divergent trend. The trends of crude-oil and cracking capacities for 1934 were similar in that new construction as of January 1 showed a drastic decline in each case. The daily average quantity of fresh feed charged to stills on January 1, 1935 was about 1,334,000 barrels, which, when divided by the operating capacity on that date, indicates an operating ratio of 70 percent. This is slightly higher than the ratio for the straight-distillation equipment and 5 percent higher than the cracking ratio for a year ago. California, which until recently did not crack to any extent, was credited with most of the gain in the total charging capacity.

The increase in the relative importance of "own" or unlicensed cracking units was continued in 1934. The total capacity of the "own" units on January 1, 1935 was 506,150 barrels daily, or more than any other single type. In connection with the capacity of "own" units it should be noted that in this survey certain types previously listed under the general titles of "pressure coke", "coil cracker", etc., have been reclassified as "own."

The construction of units for use solely as re-formers to increase the anti-knock ratio continued in the slump which began in 1933, when it was found that, in general, gasoline of the desired quality could be obtained more cheaply in other ways. The total capacity of the re-forming units on January 1, 1935 was 43,900 barrels of charging stock daily, which, when compared with a capacity of 66,000 barrels reported a year ago, indicates little or no new construction in 1934 and continued conversion of these units to straight crackers.

EXPLANATION OF SYMBOLS AND ABBREVIATIONS USED IN TABLES

Location: The location given is the plant location, which does not always correspond with the office address.

Capacity: Straight distillation.- In general, the capacity of a refinery represents the daily average crude throughput of the plant in complete operation.
Cracking.- The capacity of a cracking plant is usually given as the maximum daily throughput of fresh charging stock.

Status: Op. denotes that the plant was operating on Jan. 1, 1935; similarly, S.d. denotes shut down, and Bldg. denotes building.

Types: Refineries (straight-distillation equipment) are differentiated into types according to the products generally made. Eight common types of refineries are given in this survey as follows:

Skimming plant (Skim.)	Skimming and lube (S & L)	Complete plant (Comp.)	Skimming and asphalt (S & A)
Gasoline	Gasoline	Gasoline	Gasoline
Kerosene	Kerosene	Kerosene	Kerosene
Gas oil and fuel oil	Gas oil and fuel oil	Gas oil and fuel oil	Gas oil and fuel oil
	Lubricating oils	Lubricating oils	Asphalt
		Wax, if present in the crude	

Skimming, lube, and asphalt (S, L, & A)	Lube plant (Lube)	Asphalt plant (Asph.)	Topping plant (Top.)
Gasoline	Gas oil and fuel oil	Distillates	Tops
Kerosene	Lubricating oils	Gas oil and fuel oil	Distillates
Gas oil and fuel oil		Asphalt	Gas oil and fuel oil
Lubricating oils			
Asphalt			

"Type" used in connection with cracking plants generally represents the manufacturer's designation for the process.

In order to show the connection between this census and the refinery districts as recognized in the refinery statistics of the Bureau of Mines, the following symbols have been attached to the refineries to indicate the divisions to which they have been assigned:

a/ East coast
b/ Appalachian
c/ Indiana, Illinois, Kentucky, etc.
d/ Oklahoma, Kansas, Missouri, etc.
e/ Texas Inland
f/ Texas Gulf coast
g/ Louisiana Gulf coast
h/ Arkansas and Louisiana Inland
i/ Rocky Mountain
j/ California

The footnote * used in the survey indicates that no report was received for January 1, 1935. The information given is taken from the previous survey or from trade sources.

Recapitulation of Refineries by Years, 1914-35, and by Districts and Types, January 1, 1935

	Number				Capacity (barrels per day)			
	Op.	S.d.	Bldg.	Total	Operating	Shut down	Building	Total
Date								
Jan. 1, 1914[1]	(2/)	(2/)	(2/)	176	(2/)	(2/)	(2/)	(2/)
Jan. 1, 1918	(2/)	(2/)	(2/)	267	(2/)	(2/)	(2/)	1,186,155
Jan. 1, 1919	(2/)	(2/)	(2/)	289	(2/)	(2/)	(2/)	1,295,115
Jan. 1, 1920	[3]373	(3/)	99	472	[3]1,530,565	(3/)	263,500	1,794,065
Jan. 1, 1921	350	65	44	459	1,794,395	94,405	76,600	1,965,400
Jan. 1, 1922	325	154	30	509	1,854,590	254,610	59,950	2,169,150
Nov. 1, 1924	357	190	8	555	2,480,922	333,410	18,200	2,832,532
Jan. 1, 1925	357	184	6	547	2,489,927	337,910	37,000	2,864,837
May 1, 1925	365	185	4	554	2,511,817	342,025	11,000	2,864,842
Jan. 1, 1926	352	158	2	512	2,562,357	290,610	5,500	2,858,467
Jan. 1, 1927	327	138	7	472	2,834,282	226,725	61,000	3,122,007
Jan. 1, 1928	326	97	5	428	3,036,125	214,255	22,000	3,272,380
Jan. 1, 1929	341	72	14	427	3,325,890	183,650	99,000	3,608,540
Jan. 1, 1930	358	54	8	420	3,634,825	130,760	37,200	3,802,785
Jan. 1, 1931	346	89	10	445	3,706,610	236,075	45,000	3,987,685
Jan. 1, 1932	365	108	6	479	3,624,992	389,616	8,720	4,023,328
Jan. 1, 1933	372	133	18	523	3,445,118	444,392	31,545	3,921,055
Jan. 1, 1934	454	137	13	604	3,553,569	364,648	44,450	3,962,667
Jan. 1, 1935	435	196	7	638	3,614,749	443,751	13,900	4,072,400
Districts, Jan. 1, 1935								
East coast	25	......	1	26	613,500	......	6,000	619,500
Appalachian	42	11	......	53	163,650	15,000	......	178,650
Ind., Ill., Ky., etc.	46	8	2	56	445,870	14,900	2,500	463,270
Okla., Kans., Mo., etc.	54	33	......	87	425,565	76,739	......	502,304
Texas Inland	91	83	2	176	293,859	183,840	5,100	482,799
Texas Gulf coast	19	2	......	21	613,000	10,500	......	623,500
La. Gulf coast	5	......	......	5	138,000	......	......	138,000
Ark. and La. Inland	13	14	1	28	77,300	45,650	100	123,050
Rocky Mountain	76	36	1	113	84,570	15,922	200	100,692
California	64	9	......	73	759,435	81,200	......	840,635
Total	435	196	7	638	3,614,749	443,751	13,900	4,072,400
Types, Jan. 1, 1935								
Skimming (Skim.)	271	170	7	448	1,080,254	397,376	13,900	1,491,530
Complete (Comp.)	79	3	......	82	1,821,650	10,000	......	1,831,650
Skimming and lube (S & L)	24	6	......	30	304,400	5,600	......	310,000
Skimming and asphalt (S & A)	33	1	......	34	303,400	1,200	......	304,600
Skimming, lube, and asphalt (S, L, & A)	1	......	......	1	20,000	......	......	20,000
Lube (Lube)	6	4	......	10	2,870	13,140	......	16,010
Asphalt (Asph.)	11	4	......	15	44,200	3,300	......	47,500
Topping (Top.)	10	8	......	18	37,975	13,135	......	51,110
Total	435	196	7	638	3,614,749	443,751	13,900	4,072,400

NOTE:- See page 3 for explanation of abbreviations and symbols.

[1]From the Bureau of the Cenus.

[2]Not available.

[3]Inoperative plants included under operating.

Recapitulation of Refineries by States, January 1, 1935

State	Number				Capacity (barrels per day)			
	Op.	S.d.	Bldg.	Total	Operating	Shut down	Building	Total
Alabama	1			1	4,000			4,000
Arkansas	6	3		9	38,250	10,500		48,750
California	64	9		73	759,435	81,200		840,635
Colorado	7	2		9	6,070	1,860		7,930
Delaware	1			1	2,000			2,000
Georgia	2			2	9,000			9,000
Illinois	10	2		12	121,750	8,500		130,250
Indiana	6			6	192,700			192,700
Kansas	21	5		26	163,545	7,500		171,045
Kentucky	9	3		12	25,600	2,900		28,500
Louisiana	11	7	1	19	173,050	32,150	100	205,300
Maryland	3			3	55,000			55,000
Massachusetts	2			2	30,000			30,000
Michigan	12	3	2	17	32,550	3,500	2,500	38,550
Mississippi		4		4		3,000		3,000
Missouri	1	2		3	16,500	5,500		22,000
Montana	19	12		31	16,933	8,480		25,413
Nebraska	2	3		5	248	225		473
New Jersey	6		1	7	261,000		6,000	267,000
New Mexico	10			10	7,400			7,400
New York	6	2		8	56,700	850		57,550
Ohio	12	2		14	109,420	2,500		111,920
Oklahoma	32	26		58	245,520	63,739		309,259
Pennsylvania	34	6		40	295,750	9,150		304,900
Rhode Island	2			2	7,000			7,000
South Carolina	1			1	6,500			6,500
South Dakota	6			6	287			287
Tennessee	1			1	50			50
Texas	110	85	2	197	906,859	194,340	5,100	1,106,299
Utah	2	3	1	6	7,500	1,300	200	9,000
Virginia	1			1	2,000			2,000
West Virginia	5	1		6	16,000	2,500		18,500
Wyoming	30	16		46	46,132	4,057		50,189
Total	435	196	7	638	3,614,749	443,751	13,900	4,072,400

Recapitulation of Pipe Stills, January 1, 1934 and 1935

	Number of units		Daily charging capacity (bbl.)	
	Jan. 1, 1934	Jan. 1, 1935	Jan. 1, 1934	Jan. 1, 1935
Operating	607	596	2,589,666	2,664,746
On crude	418	421	1,907,360	2,020,880
On lube stocks	64	66	139,552	156,034
On pressure distillate	63	48	265,800	259,650
On other oils	62	61	276,954	228,182
Shut down	86	108	333,298	350,298
Building	6	5	27,450	9,300
Total	699	709	2,950,414	3,024,344

Recapitulation of Cracking Plants, by Years, 1925-35, and by Districts and States, January 1, 1935

	Charging capacity (barrels per day)			
	Operating	Shut down	Building	Total
Date				
June 1, 1925	690,492	26,200	116,000	832,692
June 1, 1926	844,800	47,690	47,600	940,090
Jan. 1, 1928	1,013,000	253,000	22,000	1,288,000
Jan. 1, 1929	1,194,501	147,923	134,450	1,476,874
Jan. 1, 1930	1,419,200	139,840	149,900	1,708,940
Jan. 1, 1931	1,594,990	244,661	111,130	1,950,781
Jan. 1, 1932	1,603,809	394,585	48,587	2,046,981
Jan. 1, 1933	1,580,051	417,694	33,650	2,031,395
Jan. 1, 1934	1,712,629	377,735	59,300	2,149,664
Jan. 1, 1935	1,897,778	311,491	20,000	2,229,269
Districts, Jan. 1, 1935				
East coast	443,372	93,285	....	536,657
Appalachian	68,864	7,100	500	76,464
Ind., Ill., Ky., etc.	282,774	38,106	8,000	328,880
Okla., Kans., Mo., etc.	219,370	43,950	....	263,320
Texas Inland	141,798	33,400	5,000	180,198
Texas Gulf coast	383,050	10,100	....	393,150
La. Gulf coast	48,000	30,000	....	78,000
Ark. and La. Inland	33,000	13,700	....	46,700
Rocky Mountain	40,700	4,700	....	45,400
California	236,850	37,150	6,500	280,500
Total	1,897,778	311,491	20,000	2,229,269
States, Jan. 1, 1935				
Arkansas	8,000	7,700	....	15,700
California	236,850	37,150	6,500	280,500
Colorado	2,850	450	....	3,300
Georgia	3,600	....	....	3,600
Illinois	80,324	10,506	8,000	98,830
Indiana	134,900	19,100	....	154,000
Kansas	102,070	14,700	....	116,770
Kentucky	12,800	....	....	12,800
Louisiana	73,000	36,000	....	109,000
Maryland	56,572	3,000	....	59,572
Massachusetts	28,500	10,800	....	39,300
Michigan	7,400	....	....	7,400
Missouri	16,000	10,500	....	26,500
Montana	4,800	1,000	....	5,800
New Jersey	174,800	71,785	....	246,585
New Mexico	500	....	....	500
New York	15,000	6,000	....	21,000
Ohio	65,350	9,600	....	74,950
Oklahoma	101,300	18,750	....	120,050
Pennsylvania	193,750	7,700	500	201,950
Rhode Island	4,000	....	....	4,000
Texas	524,848	43,500	5,000	573,348
Utah	8,400	1,000	....	9,400
West Virginia	18,014	....	....	18,014
Wyoming	24,150	2,250	....	26,400
Total	1,897,778	311,491	20,000	2,229,269

NOTE.- See page 3 for explanation of abbreviations and symbols.

Recapitulation of Cracking Plants by Types of Process, January 1, 1935

Type of process	Charging capacity (barrels per day)			
	Operating	Shut down	Building	Total
Biddison-Boyd	4,000			4,000
Black	16,000			16,000
Burton	850	8,450		9,300
Clark	600			600
Cross	182,100	39,200		221,300
de Florez	28,700			28,700
Doherty	28,500	3,500		32,000
Donnelly	30,500	9,500		40,000
Dubbs	181,998	45,600	8,500	236,098
Fleming	800			800
Foster-Wheeler	1,000			1,000
Gyro	18,000	6,000		24,000
Holmes-Manley	252,144	19,556		271,700
Isom		1,300		1,300
Jenkins	5,800	32,800		38,600
Kellogg	45,000			45,000
Koontz	20,000			20,000
Leamon		250		250
Lewis	5,400			5,400
Link	34,000	11,600		45,600
Muehl		1,500		1,500
Ormont				
Own	466,050	28,600	11,500	506,150
Pratt	3,400			3,400
Richmond	118,500			118,500
Rowsey	1,000	500		1,500
Solar	4,000			4,000
True vapor phase	6,000	1,850		7,850
Trumble		500		500
Tube and Tank	386,086	90,285		476,371
Vapor phase (miscellaneous)	9,850	4,000		13,850
Wade	500			500
Winkler-Koch	47,000	6,500		53,500
Total	1,897,778	311,491	20,000	2,229,269

Company	Location	Railroads	Straight distillation			Cracking		
			Cap.	Status	Type	Cap.	Status	Type
ALABAMA g/								
Coastal Pet. Corp. ..	Mobile	AT&N	4,000	Op. ...	Skim.			
			4,000					
ARKANSAS h/								
Berry Asphalt Co.	Waterloo	Reader	2,000	Op.	Asph.			
Henry H. Cross Co. ..	Smackover	MoP	10,000	Op.	S&L ..	1,500	S.d. ..	Donnelly.
Houston Oil Co. of Texas.	Camden	St.L&SW	5,500	S.d. ..	Skim.	2,000	S.d.	Dubbs.
Lion Oil Refg. Co. ..	El Dorado	E&W,MoP,RI	11,000	Op.	S&A....	4,500	Op.	Own.
Macmillan Pet. Corp.	Norphlet	MoP	2,500	Op.	S&L....			
Ouachita Valley Refg. Co.	El Dorado	MoP,RI	*2,000	S.d. ..	Skim.			
Root Refg. Co.	do.	MoP	12,000	Op.	do.	3,500	Op.	Own.
Do.	do.					1,500	S.d. ..	Dubbs.
Simms Oil Co.	Smackover	MoP	3,000	S.d. ..	Skim.	2,700	S.d. ..	Cross.
Stephens Refg. Co. ..	Stephens	St.L&SW	750	Op.	do.			
			48,750			15,700		
CALIFORNIA i/								
Ajax Oil & Refg. Co.	Clearwater	PE	2,500	Op.	Skim.			
American Oil Refg. Co.*	Long Beach		1,500	Op.	do.			
Associated Oil Co. ..	Associated	SP	52,000	Op.	Comp.	21,000	Op.	Tube and Tank.
Do.	Watson	None	9,500	Op.	Top.			
B & F Oil & Refg. Co.	Venice	PE	2,000	Op.	Skim.			
Bachmann Pet. Corp.	Long Beach	None	2,500	Op.	do.			
Bell View Oil Syndicate.*	Santa Fe Spgs.		2,500	Op.	do.			
R. R. Bush Oil Co. ..	Long Beach	None	3,500	Op.	do.			
Caminol Co. Ltd.	Hanford	Santa Fe....	2,500	Op.	do.			
Do.	Santa Fe Spgs.	do.	3,500	Op.	do.			
Capitol Crude Oil Co. of Los Angeles.	Santa Paula	SP	160	Op.	do.			
Casmite Co.	Casmalia	SP	1,000	Op.	Asph.			
Eagle Oil & Refg. Co.	Santa Fe Spgs.	Santa Fe....	1,500	Op.	Skim.			
Edington Oil & Refg. Co. Ltd.	Long Beach	UP	4,000	Op.	do.			
Elm Oil Co. Ltd.	do.		1,800	Op.	do.			
Envoy Pet. Co.*	do.		3,000	Op.	do.			
Estado Pet. Corp. Ltd.	do.	PE	6,000	Op.	do.			

Company	Location	Railroads	Straight distillation			Cracking		
			Cap.	Status	Type	Cap.	Status	Type
CALIFORNIA j/ (Cont'd)								
Exeter Oil Co.*	Hynes	UP	10,000	Op.	S&A			
General Pet. Corp. of Calif.	Lebec	None	12,000	Op.	Top.			
Do.	Los Angeles	Santa Fe	30,000	Op.	Comp.			
Do.	Torrance	do.	35,000	Op.	Skim.	6,000	Op.	Kellogg.
Gilmore Oil Co.	Los Angeles	SP, Santa Fe, UP.	1,500	Op.	S&A			
Do.	Roadamite	SMV	700	Op.	do.			
Golden Bear Oil Co. Ltd.	Oildale	Santa Fe, SP.	500	Op.	Asph.			
Hancock Oil Co. of Calif.	Long Beach	UP	15,000	Op.	Skim.			
Interstate Oil Corp.	Taft	Sunset	250	Op.	do.			
Kolingo Refg. Co.*	Coalinga		225	Op.	Lube.			
Lake View Oil & Refg. Co.	Maricopa	Sunset	3,000	Op.	Skim.			
Los Angeles Refg. Co.*	Los Angeles		1,000	Op.	do.			
Macmillan Pet. Corp.	Signal Hill	PE	7,500	Op.	do.			
McCallen, M. M., Refg. & Prod. Co.	Huntington Beach	None	1,200	S.d.	S&A			
McOwen, H. A., Refg. Co.*	Long Beach		1,000	Op.	Skim.			
Mohawk Pet. Co.*	Bakersfield		3,500	Op.	do.	6,500	Bldg.	Own.*
Monarch Refineries, Ltd.	Venice	PE	3,000	Op.	do.			
The Norwalk Co.	Maricopa	Santa Fe, SP.	4,000	Op.	do.			
Olympic Refg. Co.	Long Beach	None	6,500	Op.	do.			
Paraffine Companies, Inc.	Emeryville	SP	1,200	Op.	Asph.			
Petrol Corp.	Los Angeles	Santa Fe, UP.	7,000	Op.	S&A			
Rice Ranch Oil Co.	Santa Maria	None				600	Op.	Clark.
Richfield Oil Co. of Calif.	Bakersfield	Santa Fe	2,000	S.d.	Skim.			
Do.	Hynes	UP	55,000	S.d.	do.	14,000	Op.	Cross.
Do.	Los Angeles	Santa Fe	4,000	S.d.	do.			
Do.	Watson	PE	40,000	Op.	Comp.	16,000	Op.	Black.
Rio Grande Oil Co.	Vinvale	SP, UP	10,000	Op.	Skim.	3,500	Op.	Own.
San Fernando Refg. Co.	Newhall	None	2,000	Op.	S&A			
Seal Beach Oil & Refg. Co.*	Seal Beach		2,500	Op.	Skim.			

Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
CALIFORNIA i/ (Cont'd)								
Seaside Oil Co.	Summerland	SP	500	S.d.	Asph.			
Do.	Ventura	SP	5,000	Op.	S&A			
Shell Oil Co.	Coalinga	SP	3,800	Op.	Skim.			
Do.	Dominguez	PE				30,450	Op.	Dubbs.
Do.	do.	PE				4,350	S.d.	Do.
Do.	Martinez	SP	36,500	Op.	Comp.	9,600	Op.	Do.
Do.	do.	SP				7,200	S.d.	Do.
Do.	Wilmington	PE, Santa Fe.	35,000	Op.	Comp.	18,400	S.d.	Do.
Signal Oil & Gas Co. of Calif.	Hynes	UP	6,000	S.d.	Skim.			
Socal Oil & Refg. Co.	Huntington Beach	PE, SP	3,000	Op.	do.			
Standard Gasoline Co.	Taft	SP	1,500	Op.	do.			
Standard Oil Co. of Calif.	Bakersfield	Santa Fe, SP.	25,000	Op.	S&A			
Do.	El Segundo	PE, Santa Fe.	100,000	Op.	Comp.	77,600	Op.	Richmond.
Do.	Richmond	Santa Fe, SP.	100,000	Op.	do.	40,900	Op.	Do.
Walter Steiner Refg. Co.	Long Beach	UP	1,500	Op.	S&L			
Sterling Oil & Refg. Co.*	Bell		1,500	Op.	Skim.			
St. Helens Pet. Co. Ltd.	West Whittier	UP	4,500	Op.	S&A			
Super Asphalt Products Co. (Italo).	Long Beach	PE	1,500	Op.	Asph.			
The Texas Co. (Calif.)	Coalinga	SP	500	S.d.	Top.			
Do.	Fillmore	SP	4,000	Op.	Comp.	2,700	Op.	Cross.
Do.	Los Angeles	SP	30,000	Op.	Skim.	5,500	Op.	Holmes-Manley.
Triangle Oil & Refg. Co. Ltd.	Venice	PE	3,000	Op.	do.			
Union Oil Co. of Calif.	Avila	PC	10,000	S.d.	do.			
Do.	Maltha	Santa Fe, SP.	5,000	Op.	S&A			
Do.	Oleum	SP	17,000	Op.	Comp.			
Do.	Santa Paula	SP	1,200	Op.	Skim.			
Do.	Wilmington	FE	51,000	Op.	Comp.	9,000	Op.	Cross.
Do.	do.	FE				3,000	S.d.	Do.

Company	Location	Railroads	Straight distillation Cap.	Straight distillation Status	Straight distillation Type	Cracking Cap.	Cracking Status	Cracking Type
CALIFORNIA i/ (Cont'd)								
Western Oil & Refg. Co. (Nevada).	Wilmington	PE	12,000	Op.	Skim.	4,200	S.d.	Jenkins.*
White Star Ref. Co.*	Long Beach		2,000	S.d.	do.			
C. A. Williamson*	Artesia		600	Op.	do.			
Wilshire Oil Co. Inc.	Los Angeles	Santa Fe	20,000	Op.	do.			
			840,635			280,500		
COLORADO i/								
Berthoud Refg. Co.*	Berthoud	None	90	Op.	Skim.			
Colorado-Midland Refineries, Inc.	Denver	C&S	1,800	S.d.	Asph.			
Continental Oil Co.	do.	CB&Q,UP	1,500	Op.	Skim.	1,000	Op.	Cross.
Do.	Florence	D&RGW, Santa Fe.	*3,000	Op.	do.	850	Op.	Burton.
Do.	do.					450	S.d.	Do.
Fleming Oil, Gas & Refg. Co.*	Boulder		100	Op.	Top.			
Ketner Refinery	Mancos Creek	None	60	S.d.	Skim.			
McGarr Pet. Corp.	Marvel	None	180	Op.	do.			
Raven Oil & Refg. Co.	Rangely	None	200	Op.	do.			
The Texas Co.	Craig	D&SL	1,000	Op.	do.	1,000	Op.	Holmes-Manley.
			7,930			3,300		
DELAWARE a/								
The Texas Co.	Claymont	PRR,P&R	2,000	Op.	Asph.			
			2,000					
GEORGIA a/								
The Atlantic Refg. Co.	Brunswick	ACL,So	5,000	Op.	S&A	3,600	Op.	Lewis.
Mexican Pet. Corp. of Ga.	Savannah	S&A	4,000	Op.	Asph.			
			9,000			3,600		
ILLINOIS c/								
Calumet Refg. Co.*	Burnham	BOCT	750	Op.	Lube.			
Henry H. Cross Co.	Dupo	E.St.L, C&W.	1,000	Op.	Skim.			
Do.	Joliet	EJ&E	2,000	Op.	do.			
The Globe Oil & Refg. Co.	Lemont	C&A,Santa Fe.	12,000	Op.	do.	6,000	Op.	Winkler-Koch.
Indian Refg. Co., Inc.	Lawrenceville	B&O,CCC& St.L.	16,000	Op.	Comp.	5,500	Op.	de Florez.

Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
ILLINOIS c/ (Cont'd)								
Indian Refg. Co., Inc.	Lawrenceville					1,000	S.d.	Cross.
Do.						800	Op.	Do.
Lincoln Oil Refg. Co.	Robinson	CCC&St.L, IC.	10,000	Op.	S&A	12,000	Op.	Holmes-Manley.
Peerless Oil Co.	Blue Island	B&O	3,000	S.d.	Top.			
Shell Pet. Corp.	Wood River	C&A,IT,CCC &St.L.	38,000	Op.	Comp.	11,600	Op.	Dubbs.
Do.	do.					*4,000	Op.	Cross.
Do.	do.					*6,000	Op.	TVP.
Do.	do.					8,000	Bldg.	Dubbs.
Do.	do.					*2,000	S.d.	Cross.
Do.	do.					1,850	S.d.	TVP.
Socony-Vacuum Oil Co., Inc.	E. St. Louis	A&S	5,000	Op.	Skim.	3,400	Op.	Pratt.
Do.	Wood River	IT	5,500	S.d.	do.	2,000	S.d.	Dubbs.
Standard Oil Co. (Ind.)	do.	C&A,CCC& St.L,IT.	17,000	Op.	Comp.	14,624	Op.	Holmes-Manley.
Do.	do.					3,656	S.d.	Do.
The Texas Co.	Lockport	C&A,Santa Fe.	20,000	Op.	SL&A	2,000	Op.	de Florez.
Do.	do.					12,000	Op.	Holmes-Manley.
Do.	do.					2,400	Op.	Own.
			130,250			98,830		
INDIANA c/								
Empire Oil & Refg. Co.	E. Chicago	BOCT,EJ&E, IHB.	25,000	Op.	Skim.	15,000	Op.	Doherty.
Shell Pet. Corp.	do.	IHB	28,500	Op.	S&A	22,000	Op.	Dubbs.
Sinclair Refg. Co.	do.	IHB,PRR, BOCT,EJ&E	40,000	Op.	Comp.	27,000	Op.	Own.
Do.	do.					1,500	S.d.	Do.
Standard Oil Co. (Ind.)	Whiting	BOCT,EJ&E, IHB,PRR, NYC.	93,000	Op.	Comp.	57,400	Op.	Holmes-Manley.
Do.	do.					12,600	S.d.	Do.
Do.	do.					5,000	S.d.	Own.
Do.	do.					10,000	Op.	Do.
Troy Refg. Corp.*	Troy	None	200	Op.	Skim.			
Wadhams Oil Co.	E. Chicago	IHB,PRR	6,000	Op.	do.	2,000	Op.	Jenkins.
Do.	do.					1,500	Op.	Vapor phase.
			192,700			154,000		

Company	Location	Railroads	Straight distillation			Cracking		
			Cap.	Status	Type	Cap.	Status	Type
KANSAS d/								
Barnsdall Oil Co.	Wichita....................	MV, Santa Fe.	5,000	Op.	Skim.	1,500	Op. ...	Dubbs.
Bonner Refg. Co.*......	Gorham....................	UP................	250	S.d. ..	Top.	....	....	....
The Derby Oil Co.* ...	Wichita....................	Frisco, KCM&O, MoP, RI.	8,000	Op.	Skim.	2,500	Op. ...	Dubbs.
The Dickey Refg. Co.	McPherson................	Santa Fe, RI, MoP, UP	3,500	Op.	do.	1,500	Op. ...	Own.
The El Dorado Refg. Co.	El Dorado................	MoP, Santa Fe.	4,500	Op.	do.	2,000	Op.	Winkler-Koch.
Falcon Refg. Co.	Great Bend.............	Santa Fe....	800	Op.	do.	....	....	....
Fredonia Oil & Refg. Co.	Fredonia..................	MoP, Santa Fe.	275	Op.	do.	....	....	....
The Globe Oil & Refg. Co.	McPherson................	MoP, RI	10,000	Op.	do.	6,000	Op.	Winkler-Koch.
Golden Rule Refg. Co.	Wichita....................	Wichita Term.	1,000	S.d. ..	do.	1,200	S.d. ..	Jenkins.
Independent Oil & Gas Co.	Kansas City............	MoP, UP.......	9,000	Op.	S&A....	3,000	Op. ...	Dubbs.
The Kanotex Refg. Co.	Arkansas City........	Frisco, Santa Fe, MoP, MV.	12,000	Op. ...	Skim.	4,500	Op. ...	Donnelly.*
Kansas Gasoline Co.	Winfield..................	MoP.............	50	Op.	do.	....	....	....
Krueger Oil & Refg. Co.*	Natoma.....................	UP................	120	Op.	do.	....	....	....
The National Refg. Co.	Coffeyville............	MKT, Santa Fe.	8,000	Op.	Comp.	4,000	Op.	Own.
The Petroleum Products Co.	Chanute....................	MKT..............	800	Op.	Skim.	....	....	....
Philgas Co.	Kansas City............	UP, MoP........	9,000	Op.	do.	8,000	Op.	Own.*
Security Pet. Co.	Chase....	Santa Fe*..	*3,100	S.d. ..	do.	....	....	....
Shell Pet. Corp.	Arkansas City........	MoP, Santa Fe, Frisco	20,000	Op.	do.	9,000	Op. ...	Dubbs.
Sinclair Refg. Co. ..	Argentine................	Santa Fe..	11,000	Op.	S&L....	9,000	Op.	Own.
Do.	Coffeyville............	MKT, MoP, Santa Fe.	12,000	Op.	Comp.	9,000	Op.	Do.
Skelly Oil Co.	El Dorado................	MoP, Santa Fe.	23,000	Op.	S&A....	15,000	Op.	Winkler-Koch.
Do.	do.	....	....	....	....	9,000	S.d. ..	Jenkins.
Do.	do.	....	....	....	....	4,000	S.d. ..	Skelly-Rittman vapor phase.
Socony-Vacuum Oil Co., Inc.	Augusta....................	Frisco, Santa Fe.	15,000	Op.	S&A....	15,000	Op.	Own.

Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
KANSAS d/ (Cont'd)								
Standard Oil Co. (Ind.)	Neodesha	Frisco, MoP	7,500	Op.	S&A	5,120	Op.	Holmes-Manley.
Do.	do.					3,450	Op.	Own.
United Oil & Refy. Co.	Hutchinson	MoP, RI, Santa Fe.	3,000	S.d.	Skim.	500	S.d.	Trumble.
Vickers Pet. Co.*	Potwin	MoP	4,000	Op.	do.	3,500	Op.	Dubbs.
Workman Oil & Refg. Co.	McCune	Frisco	150	S.d.	Skim.			
			171,045			116,770		
KENTUCKY c/								
Aetna Oil Service, Inc.	Louisville	K&IT	2,000	Op.	Skim.	800	Op.	Fleming.
Ashland Refg. Co.	Catlettsburg	C&O	4,700	Op.	S&A	2,200	Op.	Dubbs.
Bowling Green Refg. Co.	Memphis Jct.	L&N	1,500	Op.	Skim.			
Glasgow Oil & Refg. Co.	Glasgow	do.	*200	S.d.	do.			
Greenville Refg. Co., Inc.	Greenville	None	100	Op.	do.			
Latonia Refg. Corp.	Latonia	L&N	8,000	Op.	S&A	5,000	Op.	Tube and Tank
Louisville Refg. Co.	Louisville	K&IT	4,500	Op.	do.	2,200	Op.	Dubbs.
Simrall Refg. Corp.*	Horse Cave	L&N	2,600	S.d.	Skim.			
South Kentucky Pipe Line Co.	Somerset	CNO&TP	300	Op.	do.			
Stoll Oil Refg. Co., Inc.	Louisville	L&N	2,000	Op.	Comp.	*600	Op.	Own.*
The Texas Co.	Pryse	do.	2,500	Op.	Skim.	2,000	Op.	Holmes-Manley.
Wayne County Oil Co.*	Monticello		100	S.d.	do.			
			28,500			12,800		
LOUISIANA g/ h/								
Acme Refg. Co., Inc.	h/Monroe	A&LM	100	Bldg.	Skim.			
Akin Refg. Co.	h/Shreveport	T&P	250	S.d.	do.			
Bayou State Oil Corp.	h/Hosston	do.	800	Op.	Lube.			
Chalmette Pet. Corp.	g/Chalmette	KCSo	7,000	Op.	Skim.	4,000	Op.	Winkler-Koch.
Converse Refg. Co., Inc.*	h/Converse	IC, MoP	750	Op.	do.			
Griswold Refinery	h/Shreveport	KCSo	*2,000	Op.	Top.	1,000	Op.	Own.*
Cupeco Refg. Co., Inc.*	h/Alexandria	MoP	600	S.d.	Lube.			

Company	Location	Railroads	Straight distillation			Cracking		
			Cap.	Status	Type	Cap.	Status	Type
LOUISIANA g/ h/ (Cont'd)								
Louisiana Oil Refg. Corp.	h/Bossier City......	L&A, St.L& SW.	3,000	S.d. ..	Skim.	....	....	....
Do.	h/ do.	do.	23,000	Op.	do.	22,000	Op.	Tube and Tank.
Do.	h/Gas Center..........	KCSo, St.L& SW.	15,000	S.d. ..	do.	....	....	....
Oil Refineries, Inc.*	h/Haughton..............	IC...............	1,000	S.d. ..	do.	....	....	....
Pan American Pet. Corp.	g/Destrehan............	Y&MV...........	16,000	Op.	S&A....	....	....	....
Shell Pet. Corp.	g/Norco.....................	L&A, Y&MV....	21,000	Op.	do.	10,000	Op.	Dubbs.
Shoreline Oil Co.*....	h/Lewis....................	KCSo...........	1,000	Op.	Lube.	....	....	....
Shreveport Refiner-ies, Inc.*	h/Shreveport..........	T&P, Y&MV....	300	S.d. ..	Skim.	....	....	....
Spartan Refg. Co., Inc.	h/ do.	IC, T&P.......	12,000	S.d. ..	do.	6,000	S.d. ..	Gyro.
Standard Oil Co. of La.	g/Baton Rouge........	L&A, MoP......	90,000	Op.	Comp.	7,400	S.d. ..	Cross.
Do.	g/ do.	Y&MV...........	....	....	....	34,000	Op.	Link.
Do.	g/ do.	....	....	....	....	11,000	S.d. ..	Tube and Tank.
Do.	g/ do.	....	....	....	....	11,600	S.d. ..	Link.
Stanolind Oil & Gas Co.	h/Superior.............	KCSo...........	4,500	Op.	Skim.	2,000	Op.	Cross.
The Texas Co.	h/Shreveport..........	T&P.............	7,000	Op.	Top.	....	....	....
			205,300			109,000		
MARYLAND a/								
Continental Oil Co.	Baltimore................	B&O, WMd.....	10,000	Op.	Skim.	4,000	Op.	Cross.
Do.	do.	....	....	....	....	3,000	S.d. ..	Dubbs.
Pan American Refg. Corp.	do.	B&O, PRR, WMd.	8,000	Op.	Asph.	....	....	....
Standard Oil Co. of N.J.	do.	B&O, Canton, PRR, WMd.	37,000	Op.	Comp.	52,572	Op.	Tube and Tank.
			55,000			59,572		
MASSACHUSETTS a/								
Cities Service Refg. Co.	E. Braintree..........	Fore River	20,000	Op.	Comp.	4,500	Op.	Doherty.
Do.	do.	....	....	....	....	1,800	S.d. ..	Holmes-Manley.

Company	Location	Railroads	Straight distillation			Cracking		
			Cap.	Status	Type	Cap.	Status	Type
MASSACHUSETTS a/ (Cont'd)								
Colonial Beacon Oil Co., Inc.	Everett	B&A, B&M	10,000	Op.	S&A	24,000	Op.	Tube and Tank.
Do.	do.					9,000	S.d.	Do.
			30,000			39,300		
MICHIGAN c/								
Bay Refg. Co.	Bay City	None	500	Bldg.	Skim*			
Central Michigan Refg. Co.	St. Louis	None	400	Op.	S&L*			
Henry H. Cross Co.	Muskegon	PM	1,000	S.d.	Skim.			
Kent Refg. Co.	Dewey	GT	750	Op.	do.			
Keystone Oil Refg. Co.	Detroit	PRR, Wabash	2,000	Op.	do.			
McClanahan Refineries, Inc.	St. Louis	PM	2,000	Bldg.	do.			
Midwest Refineries, Inc.	Alma	AA, PM	2,000	Op.	do.			
Naph-Sol Refg. Co.	Muskegon	PM	2,500	Op.	do.			
Old Dutch Refg. Co.	do.	GT	3,000	Op.	do.			
Peerless Oil Co.*	Big Rapids	PM	1,000	S.d.	do.			
Do.	Saginaw	PM	800	Op.	do.			
The Pure Oil Co.	Midland	PM, MC	3,000	Op.	do.			
Roosevelt Oil Co.	Mt. Pleasant	AA, PM	6,000	Op.	S&L			
Socony-Vacuum Oil Co., Inc.	Trenton	DT&I	10,500	Op.	Skim.	3,500	Op.	Own.
Do.	do.					3,900	Op.	Dubbs.
Standard Oil Co. (Ind.)	Zilwaukee	GT, MC, PM	1,500	S.d.	Skim.			
Superior Oil Corp.	Elsie	AA	1,000	Op.	do.			
Sweet Oil Refg. Co.	Wyman	PM	600	Op.	do.			
			38,550			7,400		
MISSISSIPPI h/								
Dixie Oil & Refg. Co.*	Jackson	IC	1,000	S.d.	Skim.			
East Jackson Refg. Co., Inc.	do.	GM&O, IC	500	S.d.	Asph.			
Jackson Oil & Refg. Co.*	Rankin	IC, C&MV, G&SI.	1,000	S.d.	do.			
Parke Oil & Refg. Co.*	Dixon	IC	500	S.d.	do.			
			3,000					

Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
MISSOURI d/								
Altitude Pet. Corp. of Mo.*	Kansas City	KCSo	4,000	S.d.	Skim.	1,000	S.d.	Burton.
Do.	do.					1,500	S.d.	Muehl.
Joplin Refg. Co.*	Joplin	Frisco, MoP	1,500	S.d.	Skim.	1,000	S.d.	Jenkins.
Standard Oil Co. (Ind.)	Sugar Creek	KCSo, Santa Fe.	16,500	Op.	Comp.	16,000	Op.	Holmes-Manley.
Do.	do.					7,000	S.d.	Burton.
			22,000			26,500		
MONTANA i/								
Arro Oil & Refg. Co.	W. Lewistown	CMStP&P, GN	1,500	S.d.	Skim.	800	S.d.	Dubbs.
B & M Refg. Co.	Roundup	CMStP&P	300	Op.	do.			
Bear Den Refinery*	Bear Den		25	Op.	do.			
Big Horn Oil & Refg. Co.*	Billings	CB&Q, GN, NP	1,000	Op.	do.			
Big West Oil Co. of Mont.	Kevin	GN	800	Op.	do.	500	Op.	Dubbs.
Conrad Refg. Co.	Conrad	GN	1,000	S.d.	do.			
Consumers Refg. Co.	Collins	GN	500	S.d.	do.			
Continental Oil Co.	Lewistown	CMStP&P	1,500	Op.	do.			
Cut Bank Refg. Co.	Cut Bank	None	250	S.d.	do.			
Deloraine Refg. Co.	Oilmont	None	250	Op.	do.			
Dunlap Refinery	Cat Creek	None	75	Op.	Top.			
Hart Refineries	Hedgesville	GN	100	Op.	Skim.			
Do.	Missoula	CMStP&P, NP	300	Op.	do.			
Ted Hawley	Gallup City	None	50	S.d.	do.			
Hole Brothers	Cut Bank	GN	250	S.d.	Top.			
Home Oil & Refg. Co.	Great Falls	GN	1,000	S.d.	Skim.			
Eugene Hunt*	Winnett		200	Op.	do.			
Independent Refg. Co.	Laurel	CB&Q, GN, NP	5,000	Op.	do.	1,500	Op.	Donnelly.
International Refg. Co.	Sunburst	GN	3,000	Op.	do.	2,000	Op.	de Florez.
Lewis Refineries*	Valentine		50	S.d.	do.			
C. A. McKeehan	Molt	None	5	Op.	do.			
Minnesota-Flatwillow Pet. Co.	Cat Creek	None	8	Op.	do.			
Red Lodge Refinery	Red Lodge	None	70	Op.	do.			
Regal Products Co.*	Soap Creek field		50	S.d.	do.			
The Russell Oil Co.	Billings	GN, NP	1,000	Op.	do.			
Do.	Butte	CMStP&P, NP	500	Op.	do.			
Snow Cap Oil Co.	Sunburst	GN	330	S.d.	do.	200	S.d.	Own.
Sunburst Oil & Refg. Co.	Great Falls	CMStP&P, GN	*3,000	S.d.	do.			

Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
MONTANA i/(Cont'd)								
Unity Pet. Corp.	Kalispell..............	GN..............	800	Op.	Skim.	800	Op.	Vapor phase.
Yale Oil Corp. of S.D.*	Billings................	CB&Q,GN,NP	2,000	Op.	S&A....	....	....	....
Do.	Miles City............	CMStP&P,NP	500	S.d. ..	Skim.	....	....	....
			25,413			5,800		
NEBRASKA i/								
Terry Carpenter*.......	Scottsbluff...........	CB&Q...........	150	Op.	Skim.	....	....	....
Chadron Refinery.......	Chadron.................	C&N............	98	Op.	do.	....	....	....
Harrison Refg. Co. ..	Harrison................	C&NW...........	50	S.d. ..	do.	....	....	....
Midland Refg. Corp.	Crawford................	do.	125	S.d. ..	do.	....	....	....
State Line Refy.	Mitchell................	CB&Q...........	50	S.d. ..	do.	....	....	....
			473					
NEW JERSEY a/								
The Barber Asphalt Co.	Maurer....................	CRRNJ,PRR..	7,500	Op.	S&A....	....	....	....
The Bertrin Pet. Co.	do.	do.	....	....	....	2,000	Op.	Cross.
Crew Levick Co.	Petty Island..........	PRR............	10,000	Op.	Skim.	7,500	Op.	Doherty.
Do.	do.	....	....	....	....	1,500	S.d. ..	Do.
Middlesex Refg. Co.	Picataway..............	LV..............	6,000	Re-bldg.	Skim.	....	....	....
Socony-Vacuum Oil Co., Inc.	Paulsboro..............	PRR............	20,000	Op.	Comp.	3,500	Op.	Cross.
Do.	do.	....	....	....	....	4,800	Op.	Tube and Tank.
Standard Oil Co. of N.J.	Bayonne, etc.	CRRNJ,LV, PRR,SIRT.	155,000	Op.	Comp.	136,000	Op.	Do.
Do.	do.	....	....	....	....	66,285	S.d. ..	Do.
Tide Water Oil Co. ..	do.	CRRNJ,EJ&T,LV.	50,000	Cp.	Comp.	21,000	Op.	Do.
Do.	do.	....	....	....	....	4,000	S.d. ..	Do.
Warner-Quinlan Co. ..	Linden....................	CRRNJ.........	18,500	Op.	S&A....	....	....	....
			267,000			246,585		
NEW MEXICO i/								
The Aerex Co.	Bloomfield............	None...........	100	Op.	Skim.	....	....	....
Basin Refg. Co.	Aztec......................	D&RGW.........	100	Op.	do.	....	....	....
Continental Oil Co.	Albuquerque...........	Santa Fe....	1,000	Op.	do.	....	....	....
Do.	Artesia....................	do.	1,500	Op.	do.	....	....	....
Do.	Farmington.............	D&RGW.........	1,000	Op.	do.	....	....	....

Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
NEW MEXICO i/ (Cont'd)								
Malco Refineries, Inc.	Artesia	Santa Fe	2,000	Op.	Skim.			
McNutt Oil & Refg. Co.	Brickland	Santa Fe, SP.	1,000	Op.	do.	500	Op.	Donnelly.
Pecos Diamond Refg. Co.	Artesia	None	300	Op.	do.			
Valley Refg. Co.	Roswell	Santa Fe	300	Op.	do.			
Walker Oil Corp.	Hobbs	None	100	Op.	do.			
			7,400			500		
NEW YORK a/ b/								
Allegany Refiners, Inc.	b/Bolivar	PS&N	1,200	Op.	S&L			
Empire State Refg. Corp., Inc.	b/ do.	do.	750	S.d.	do.			
Gulf Refg. Co.	a/Staten Island	B&O	15,000	Op.	Skim.			
Sawyer Refg. Co., Inc.	b/Wirt		100	S.d.	Top.			
Sinclair Refg. Co.	b/Wellsville	B&O, ERR	10,000	Op.	Comp.	6,000	Op.	Own.
Socony-Vacuum Oil Co., Inc.	a/Brooklyn, etc.	LIRR	19,000	Op.	do.	4,000	Op.	Cross.
Do.	a/ do.					4,000	S.d.	Do.
Do.	a/ do.					2,000	Op.	de Florez.
Do.	b/Buffalo	BCRR	5,000	Op.	Comp.	2,000	S.d.	Cross.
Do.	b/ do.					2,000	Op.	de Florez.
Do.	b/Olean	ERR, PRR	6,500	Op.	Comp.	500	Op.	Cross.
Do.	b/ do.					500	Op.	Tube and Tank.
			57,550			21,000		
OHIO b/ c/								
Allegheny Arrow Oil Co.	b/Canton	PRR, W&LE	1,500	S.d.	Skim.	850	S.d.	Dubbs.
The Canfield Oil Co.	b/Cleveland	W&LE	1,000	Op.	Comp.			
Gulf Refg. Co. (Del.)	c/Hooven	B&O, CCC& St.L.	14,000	Op.	S&A	13,000	Op.	Own.
Do.	c/Toledo	W&LE	13,000	Op.	Skim.	6,500	Op.	Do.
Do.	c/ do.					6,500	S.d.	Do.
The National Refg. Co.	c/Findlay	NYC&St.L.	3,200	Op.	Comp.	1,350	Op.	Do.
Do.	b/Marietta	B&O	700	Op.	do.			
The Peninsula Oil Co.	c/Catawba Island	None	20	Op.	Skim.			

Company	Location	Railroads	Straight distillation			Cracking		
			Cap.	Status	Type	Cap.	Status	Type
OHIO b/ c/(Cont'd)								
The Pure Oil Co.	b/Heath	B&O,NYC, PRR.	10,500	Op.	Skim.	4,000	Op.	Cross.
Do.	b/ do.					4,000	Op.	Gyro.
Do.	c/Toledo	Toledo Term.	9,500	Op.	Skim.	5,000	Op.	Do.
Do.	c/ do.					3,000	Op.	Cross.
Standard Oil Co. (Ohio).	b/Cleveland	B&O,ERR	24,000	Op.	Comp.	10,000	Op.	Tube and Tank.
Do.	c/Lima	B&O,ERR, NYC&St.L.	7,500	Op.	Skim.	4,000	Op.	Solar.
Do.	c/ do.					2,000	S.d.	Cross.
Do.	c/Toledo	Toledo Term.	12,000	Op.	Comp.	4,500	Op.	Tube and Tank.
The Stellar Refg. Co.*	b/Marne	PRR	1,000	S.d.	Skim.	250	S.d.	Leamon.
Sun Oil Co.	c/Toledo	Bay Term.	14,000	Op.	do.	10,000	Op.	Own.
			111,920			74,950		
OKLAHOMA d/								
Anderson Prichard Refg. Corp.	Cyril	Frisco	6,000	Op.	Skim.	3,500	Op.	Winkler-Koch.
Associated Oil Corp.*	Allen	KO&G	8,000	S.d.	Comp.	2,000	S.d.	Jenkins.
Barnsdall Oil Co.	Barnsdall	MV	5,000	Op.	do.	4,000	Op.	Cross.
Do.	Okmulgee	ON	11,000	Op.	Skim.	3,500	Op.	Do.
Do.	do.					1,000	S.d.	Do.
Bell Oil & Gas Co.*	Grandfield	MKT,RI	4,500	Op.	Skim.	2,000	Op.	Dubbs.
Black Gold Refg. Co.	Oklahoma City	Santa Fe	2,000	Op.	S&L	600	Op.	Own.
F. G. Breshears*	Wagoner	None	39	S.d.	Skim.			
Century Pet. Co.*	Oklahoma City	RI	2,500	S.d.	do.			
Do.*	W. Tulsa	MV	2,500	S.d.	do.			
Champlin Refg. Co.*	Enid	Frisco,RI, Santa Fe.	15,000	Op.	Comp.	3,000	Op.	Winkler-Koch.
Continental Oil Co.	Ponca City	RI,Santa Fe.	30,000	Op.	do.	4,000	Op.	Cross.
Do.	do.					9,000	Op.	Dubbs.
Do.	Sapulpa	Frisco	4,000	S.d.	Skim.	750	S.d.	Cross.
Crescent Refg. Co.*	Holdenville	Frisco,RI	1,000	S.d.	do.			
Cushing Refg. & Gasoline Co.	Blackwell	Frisco, Santa Fe.	1,700	Op.	do.			
Do.	Cushing	MKT,Santa Fe.	4,500	Op.	do.	2,200	Op.	Dubbs.
Deep Rock Oil Corp.	do.	do.	10,000	Op.	Comp.	4,000	Op.	Do.
Eason Oil Co.	Enid	Frisco, Santa Fe.	4,000	Op.	Skim.	2,000	Op.	Jenkins.

Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
CKLAHOMA d/ (Cont'd)								
Empire Oil & Refg. Co.	Cushing	MKT, Santa Fe.	5,000	S.d.	Skim.			
Do.	Okmulgee	ON, Frisco	4,000	Op.	Comp.	1,000	S.d.	Doherty.
Do.	Ponca City	RI, Santa Fe.	12,000	Op.	do.	1,500	Op.	Do.
Do.	do.					1,000	S.d.	Do.
Do.	do.					2,000	Op.	Dubbs.
The Gilmer Oil Co.	Ringling	ONM&P, Santa Fe.	1,500	S.d.	Skim.			
The Globe Oil & Refg. Co.	Blackwell	Frisco, Santa Fe.	8,000	S.d.	do.	4,000	S.d.	Winkler-Koch.
Government Refg. Co.*	Oklahoma City		600	S.d.	do.			
Do.*	do.		2,000	S.d.	S&L.			
Do.*	Seminole		800	S.d.	Skim.			
Gulf States Corp.*	Oklahoma City		3,000	S.d.	do.			
Guthrie Refg. Co.	Guthrie	Santa Fe	500	S.d.	do.			
Hanger Refg. Co.*	Oklahoma City		500	S.d.	do.			
J. C. Huckins	Earlsboro	RI	500	S.d.	do.			
Illinois Oil Co.	Cushing	MKT, Santa Fe.	3,000	S.d.	do.	1,500	S.d.	Donnelly.
Independent Oil & Gas Co.	Okmulgee	ON, Frisco	6,000	Op.	Comp.	3,000	Op.	Dubbs.
Johnson Oil Refg. Co.	Cleveland	MKT	6,000	Op.	Skim.	2,000	Op.	Dubbs.
Knox Refg. Co.	Covington	None	250	Op.	do.			
Major Pet. Products Co.	Oklahoma City	Frisco	1,500	Op.	do.			
Marathon Oil Co.	Bristow	Frisco	5,000	Op.	do.	1,500	Op.	Kellogg.
Mid-Continent Pet. Corp.	W. Tulsa	Frisco, MV, Santa Fe.	40,000	Op.	Comp.	20,000	Op.	Koontz.
Monarch Refg. Co.	Oklahoma City	ORy	*1,000	Op.	Skim.			
Oklahoma City Refg. Co.*	do.		2,000	S.d.	do.			
Cmar Refg. Co.*	Garber	RI	4,000	S.d.	do.	2,500	S.d.	Winkler-Koch.
Paramount Refg. Co.*	Oklahoma City		2,000	Op.	do.			
J. H. Peacock, Inc.*	do.		2,000	S.d.	do.			
Peppers Gasoline Co.*	do.	Frisco	500	Op.	do.			
Pilgrim, Inc.*	Kingston		70	Op.	Lube.			
Producers Oil Co.*	Bristow	do.	1,500	S.d.	Skim.			
The Pure Oil Co.	Muskogee	Frisco, MV, KO&G, MKT.	9,000	Op.	Comp.	3,500	Op.	Cross.
Do.	do.	KO&G				1,200	Op.	Gyro.

Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
OKLAHOMA d/ (Cont'd)								
Rock Island Refg.Co.	Beckett	RI	6,500	Op.	Skim.	*3,500	Op.	Winkler-Koch.
Sinclair Refg. Co.	Sand Springs	SSRR	8,000	Op.	Comp.	2,000	Op.	Cross.
Do.	do.					2,000	S.d.	Do.
Do.	W. Tulsa	Frisco, MKT, MV, Santa Fe.	4,500	S.d.	Skim.	1,500	S.d.	Dubbs.
Sun Co. of Del.	Yale	MK&T, Santa Fe.	5,000	Op.	do.			
Sunray Oil Co.	Allen	KC&G	6,000	Op.	S&A	1,600	Op.	Dubbs.
The Texas Co.	W. Tulsa	Frisco, MV	14,000	Op.	Comp.	10,000	Op.	Holmes-Manley.
Do.	do.					3,600	Op.	Own.
Tide Water Oil Co. (Okla.)	Drumright	Frisco, Santa Fe.	15,000	Op.	Skim.	7,000	Op.	Tube and Tank.
Triangle Refg. Co.*	Oklahoma City		800	S.d.	do.			
Western Oil Corp.	Beckett	RI	1,500	S.d.	do.	1,500	S.d.	Jenkins.
H. F. Wilcox Oil & Gas Co.	Bristow	Frisco	6,000	Op.	do.	1,100	Op.	Dubbs.
Wirt Franklin Pet. Corp.	Ardmore	Frisco, RI, Santa Fe.	4,000	Op.	do.			
Yale Oil Corp.	Yale	MKT, Santa Fe.	2,000	S.d.	do.			
York Refg. Co.	Oklahoma City		2,000	S.d.	do.			
			309,259			120,050		
PENNSYLVANIA a/ b/								
The Atlantic Refg. Co.	b/Franklin	ERR, NYC	9,000	Op.	Comp.	6,000	Op.	Cross.
Do.	a/Philadelphia	B&O, PRR	70,000	Op.	do.	10,000	Op.	Do.
Do.	a/ do.					1,800	Op.	Lewis.
Do.	a/ do.					10,000	Op.	de Florez.
Do.	a/ do.					11,000	Op.	Kellogg.
Do.	b/Pittsburgh	PRR	8,000	Op.	Comp.	4,000	Op.	Cross.
James B. Berry Son's Co., Inc.	b/Oil City	do.	2,500	Op.	do.			
Bradford Oil Refg. Co.	b/Bradford	B&O, ERR, PRR.	2,300	Op.	S&L			
Bradford-Penn Refg. Corp.	b/Clarendon	PRR	1,000	Op.	Comp.			
The Canfield Oil Co.	b/Coraopolis	P&LE	1,500	Op.	S&L			
The Carnegie Refg. Co.	b/Carnegie	PRR	2,000	S.d.	Comp.			

Company	Location	Railroads	Straight distillation			Cracking		
			Cap.	Status	Type	Cap.	Status	Type
PENNSYLVANIA a/ b/ (Cont'd)								
Continental Refg. Co.*	b/Oil City	PRR	1,000	Op.	Comp.			
Crew Levick Co.	b/Titusville	NYC,PRR	3,000	Op.	do.			
Daugherty Refinery	b/Petrolia	B&O	4,000	Op.	S&L			
Franklin Creek Refg. Corp.	b/Franklin	ERR	1,500	Op.	do.			
The Freedom Oil Works Co.	b/Freedom	PRR	2,500	Op.	Comp.	500	Bldg.	Dubbs.
Gulf Refg. Co.	a/Girard Pt.	do.	30,000	Op.	S&L	31,200	Op.	Own.
Do.	a/ do.					2,400	S.d.	Do.
Do.	b/Neville Isl.	P&OV	10,000	Op.	S&L	5,200	Op.	Do.
Kendall Refg. Co.	b/Bradford	B&O,ERR, PRR.	3,500	Op.	Comp.	1,400	Op.	Dubbs.
A. D. Miller Sons Co.*	b/Pittsburgh	B&O,PRR	1,000	S.d.	S&L			
Oil Creek Refg. Co.	b/Fieldmore Spgs.	NYC,PRR	1,500	Op.	Comp.			
Pennsylvania Oil Products Refg. Co.	b/Eldred	PRR	6,000	Op.	do.	500	Op.	Wade.
Pennsylvania Refg. Co.	b/Karns City	B&O	2,000	Op.	do.			
Do.	b/Titusville	NYC,PRR	2,000	Op.	S&L			
The Pennzoil Co.	b/Rouseville	ERR,NYC, PRR.	10,000	Op.	Comp.	4,500	Op.	Dubbs.
Do.	b/ do.					2,000	S.d.	Do.
The Pure Oil Co.	a/Marcus Hook	PRR,P&R	16,000	Op.	Comp.	8,800	Op.	Cross.
Do.	a/ do.					2,600	Op.	Gyro.
Pure Penn Refg. Co.*	b/Clarendon	PRR	350	S.d.	S&L			
Quaker State Oil Refg. Corp.	b/Emlenton	PRR	1,650	Op.	Comp.	750	Op.	Dubbs.
Do.	b/Farmers Valley	PS&N	3,000	Op.	do.	1,500	Op.	Do.
Republic Oil Refg. Co.	b/Coraopolis	P&LE	*4,000	S.d.	Top.*	*1,500	S.d.*	Cross.*
Sinclair Refg. Co.	a/Marcus Hook	PRR,P&R	28,000	Op.	S&L	29,500	Op.	Own.
Do.	a/ do.					1,300	S.d.	Isom.
The Sloan & Zook Refg. Co.	b/Warren	PRR	1,500	Op.	S&L			
Starlight Refg. Co.	b/Karns City	B&O	300	Op.	Skim.			
Sun Oil Co.	a/Marcus Hook	B&O,PRR, P&R.	63,000	Op.	Comp.	65,000	Op.	Own.
Superior Oil Works	b/Warren	PRR	500	Op.	do.			
Tiona Refg. Co.	b/Clarendon	do.	1,000	Op.	do.			
Ultra Penn Refg. Co.	b/Bruin	B&O	1,000	Op.	do.			
United Refg. Co.	b/Warren	PRR	3,000	Op.	do.			

Company	Location	Railroads	Straight distillation			Cracking		
			Cap.	Status	Type	Cap.	Status	Type
PENNSYLVANIA a/ b/ (Cont'd)								
Valvoline Oil Co.	b/E. Butler	B&O	2,500	Op.	Comp.			
Do.	b/Warren	PRR	1,000	S.d.	do.			
Waverly Oil Works Co.	b/Pittsburgh	do.	1,000	Op.	do.	500	S.d.	Cross.
Wolverine-Empire Refg. Co.	b/Reno	ERR, NYC	2,000	Op.	do.			
Do.	b/Tidioute	PRR	800	S.d.	S&L			
			304,900			201,950		
RHODE ISLAND a/								
Socony-Vacuum Oil Co., Inc.	E. Providence	NYNH&H	5,000	Op.	S&A	4,000	Op.	Cross.
The Texas Co.	Providence	do.	2,000	Op.	Asph.			
			7,000			4,000		
SOUTH CAROLINA a/								
Standard Oil Co. of N. J.	Charleston	ACL, SAL, So	6,500	Op.	S&A			
			6,500					
SOUTH DAKOTA i/								
Clearmont Refinery*	Clearmont		50	Op.	Skim.			
D - H Refg. Co.*	Spearfish		40	Op.	do.			
Edgemont Refg. Co.*	Edgemont	CB&Q	30	Op.	do.			
Hot Springs Refg. Co.*	Hot Springs		40	Op.	do.			
Rex Oil Refinery, Inc.	Rapid City	None	100	Op.	do.			
Sturgis Refg. Co.	Sturgis	C&NW	27	Op.	do.			
			287					
TENNESSEE c/								
The Russell Producing Co.*	Sunbright	So	50	Op.	Skim.			
			50					
TEXAS e/ f/								
Acme Refg. Co., Inc.*	e/Gladewater	None	1,250	Op.	Skim.			
Active Oil Corp.*	e/Arno		1,500	S.d.	do.			
Aero Gas Refg. Co.*	e/Pecos		225	Op.	do.			
All State Refg. Co.*	e/Thrall	I&GN	2,500	S.d.	do.			
American Oil Co.*	e/Gladewater	None	1,500	S.d.	do.			
American Pet. Co.	f/Houston	Port Term.	10,000	Op.	do.			
Amsco Refg. Co.	e/Mirando City	Tex.Mex.	2,500	Op.	S&L	1,200	Op.	Own.

Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
TEXAS e/ f/ (Cont'd)								
Apex Refg. Co. #1*....	e/Gladewater..........	T&P....	2,500	Op.	Skim.	....	....	....
Do. #2*....	e/ do.	do.	2,000	Op.	do.	....	....	....
Archer Refg. Corp. ..	e/Megargel.............	Frisco........	1,000	Op.	do.	....	....	....
Arrow Refg. & Prod. Co.	e/Overton...............	I&GN	5,000	Op.	do.	....	....	....
Artex Refg. Co. #1*..	e/Arp......................	do.	2,000	S.d. ..	do.	....	....	....
Do. #2*..	e/Camps Switch......	T&P...............	4,250	S.d. ..	do.	....	....	....
Atlantic & Gulf Refg. Co.*	e/Kilgore...............	I&GN...........	2,500	S.d. ..	do.	....	....	....
Atlantic-Pacific & Gulf Refg. Co.*	e/Wichita Falls....	FW&DC,MKT, WFS.	5,000	Op.	do.	1,500	S.d. ..	Jenkins.
Badger Oil Co.*.........	e/Amarillo.............	....	25	Op.	do.	....	....	....
Baird Refg. Co.	e/Baird..................	T&P...............	1,500	S.d. ..	do.	1,500	Op. ...	Own.
Beacon Oil & Refg. Co.*	e/Henderson...........	I&G...............	4,000	Op.	do.	....	....	....
Bee Oil & Refg. Co.	e/Pettus................	SP.................	800	Op.	Top.	....	....	....
Benco Refg. Co.*........	e/Three Rivers......	MoP...............	100	S.d. ..	Skim.	....	....	....
Big Sandy Oil & Refg. Co.*	e/Big Sandy..........	StL&SW.......	1,250	S.d. ..	do.	....	....	....
Bluebonnet Oil Refg. Co.*	e/Wickett....	T&P...............	5,000	S.d. ..	Top.	....	....	....
Blue Diamond Refg. Co.*	e/Gladewater..........	None.	1,500	S.d. ..	Skim.	....	....	....
Bobrose Oil Refg. Co.*	e/Brownwood...........	MKT,Santa Fe.	1,000	S.d. ..	do.	....	....	....
Bonita Refg. Co.*......	e/Joinerville........	None...	500	S.d. ..	do.	....	....	....
Broadmore Sales Co., Inc.*	e/Kilgore................	I&GN	4,000	S.d. ..	do.	....	....	....
C. L. & W. Refg.Co., Inc.*	e/Gladewater..........	....	1,000	Op.	do.	....	....	....
Canyon Oil &Gas Co.*	e/Cisco.....	....	400	S.d. ..	do.	....	....	....
Carson Refinery.........	e/Brady..................	Santa Fe....	70	Op.	do.	....	....	....
Century Refg. Co.* ...	e/Friars Switch.....	I&GN...........	2,500	S.d. ..	do.	....	....	....
Chapa Refinery*.........	e/Laredo.................	....	400	Op.	do.	....	....	....
Charco Redondo Refg. Co.*	e/Mirando City......	None...........	50	S.d. ..	do.	....	....	....
Chief Refg. Co.*........	e/Gladewater..........	T&P...............	1,200	S.d. ..	do.	....	....	....
Citizens Refg. Co. ..	e/Luling..................	SP.................	1,000	Op.	do.	....	....	....
Col Tex Refg. Co.	e/Colorado.............	T&P...............	12,500	Op.	do.	3,500	Op.	Dubbs.
Concho Refg. Co.	e/San Angelo.........	Santa Fe....	125	Op.	do.	....	....	....
Condor Refg. Co.*......	e/Kilgore...............	I&GN...........	2,000	S.d. ..	do.	....	....	....
Conroe Refg. Co.*......	f/Conroe................	MoP...............	500	S.d. ..	do.	....	....	....
Continental Oil Co.	e/Wichita Falls....	MKT...............	5,000	Op.	do.	2,300	Op.	Cross.
Corpus Christi Refg. Co.	f/Corpus Christi..	MoP...............	3,500	Op.	do.	....	....	....

Company	Location	Railroads	Straight distillation			Cracking		
			Cap.	Status	Type	Cap	Status	Type
TEXAS e/ f/ (Cont'd)								
Cosden Oil Corp.*	e/Big Spring	T&P	12,500	Op.	Skim.	12,500	Op.	Donnelly.
Crown Central Pet. Corp.*	f/Pasadena	Port Term.	15,000	Op.	S&L	6,000	Op.	Holmes-Manley.
Crystal Refg. Co.*	e/Kilgore	None	1,000	S.d.	Skim.			
Danciger Oil & Refineries, Inc.	e/Longview	I&GN	10,000	S.d.	do.			
Do.	e/Pampa	FW&DC, Santa Fe.	6,000	Op.	do.	4,000	Op.	Biddison-Boyd.
Deason Refg. Co.*	e/Turner Town	None	500	S.d.	do.			
East Texas Refg. Co.	e/Longview	I&GN, Santa Fe.	10,000	Op.	do.	10,000	Op.	Donnelly.
Elk Refg. Co.*	e/Kilgore	I&GN	4,000	S.d.	do.			
Empire Oil & Refg. Co.	e/Gainesville	Santa Fe, MKT.	5,000	S.d.	do.	2,000	S.d.	Dubbs.
The Exchange Pet. Corp.	e/Albany	MKT	500	Op.	do.			
Falls Refg. Co.*	e/Wichita Falls	FW&DC	2,500	Op.	do.			
Foshee Refg. Co.*	e/Gladewater	T&P	1,500	S.d.	do.			
Friar Topping and Refg. Co.*	e/Friars Switch	I&GN	2,000	Op.	do.			
Gibson Oil Corp.*	e/Magic City	FW&DC	300	Op.	do.			
Gilliland Refg. Co.*	e/Gladewater	T&P	4,000	Op.	do.	1,000	Op.	Own.
Gilmer Oil Co.	e/ do.	do.	800	S.d.	do.			
Golden Pet. Co.*	e/Ballinger		200	Op.	do.			
Golden West Oil Co.*	e/Hondo		25	Op.	Lube.			
Goodson Refg. Co.	e/Gladewater	T&P	1,400	S.d.	do.			
The Graford Refg. Co.*	e/Mineral Wells		50	Op.	do.			
Gratex Refg. Co.	e/Graham	None	300	Op.	do.			
Great West Refg.Co.*	e/Big Spring	T&P	7,500	S.d.	do.	500	S.d.	Rowsey.
Gregg Oil Products Co.*	e/Gladewater	None	1,500	S.d.	do.			
Gulf Refg. Co.	e/Ft. Worth	FW Belt	6,000	Op.	do.	6,000	Op.	Own.
Do.	f/Ft. Arthur	KCSo,SP	100,000	Op.	Comp.	53,000	Op.	Own.
Do.	e/Sweetwater	Santa Fe, T&P.	5,000	Op.	Skim.	4,000	Op.	Own.
Hall Refg. Co.*	e/Oilton	Tex. Mex.	200	S.d.	do.			
Haskell Oil Refg. Corp.*	e/Breckenridge		200	S.d.	do.			
Louis Hausman Oil Co.	e/Laredo	I&GN, Tex. Mex.	*55	Op.	do.			
Hightower Oil & Refg. Co.*	e/Brownwood		750	Op.	do.			
Hill Refg. Co.	e/Ballinger	None	40	Op.	do.			

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Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
TEXAS e/ f/ (Cont'd)								
Houston Oil Co. of Texas.	f/Viola	MoP	1,000	Op.	Skim.			
Howard County Refg. Co.	e/Big Spring	T&P	2,000	Op.	do.			
Hub Oil Refg. Co.*	e/Reeds Switch		3,000	S.d.	do.			
Humble Oil & Refg. Co.	f/Baytown	MoP,SP	115,000	Op.	S&L	55,000	Op.	Tube and Tank.
Do.	f/ do.					5,600	S.d.	Cross.*
Do.	f/Ingleside	SP	15,000	Op.	Skim.	8,000	Op.	Tube and Tank.
Do.	e/Neches	I&GN	5,000	Op.	Top.			
Do.	e/San Antonio	MoP,SP	4,500	Op.	Skim.			
Hunter & Knox Refg. Co.*	e/Reeds Switch	I&GN	750	S.d.	do.			
Ideal Refg. Co.*	e/Gladewater	None	750	S.d.	do.			
Jacksboro Refg. Co.*	e/Jacksboro		250	Op.	do.			
Jackson Refg. Co.*	e/Gladewater	None	1,750	S.d.	do.			
Johnson Refg. Co.*	e/K lgore	None	1,200	Op.	do.			
Kent Refg. Co.*	e/Angus	SP	4,000	S.d.	do.			
Kilgore Topping Co.*	e/Kilgore	I&GN	2,000	S.d.	do.			
Kil-Tex Reclamation Co.	e/Kilgore	I&GN	1,000	S.d.	do.			
Lake Refg. Co.*	e/Gladewater	None	2,000	Op.	do.			
L. & G. Refg. Co.*	e/ do.	T&P	1,250	S.d.	do.			
La Pren Refg. Co.*	e/Kilgore	I&GN	2,500	Op.	do.			
LaSalle Pet. Co.	e/Burkburnett	MKT	3,500	Op.	do.			
London Topping & Refg. Co.*	e/Overton	None	1,000	S.d.	do.			
Lone Star Refg. Co.*	e/Gladewater	T&P	2,000	Op.	do.	1,000	Op.	Own.
The Lubbock Refg. Co.*	e/Lubbock		250	S.d.	do.			
Macmillan Pet. Corp.	e/Borger	Santa Fe	*7,000	S.d.	do.			
Magnolia Pet. Co.	f/Beaumont	KCSo,SP	80,000	Op.	Comp.	55,000	Op.	Cross.
Do.	e/Corsicana	SP,StL&SW	3,500	Op.	Skim.			
Do.	e/Ft. Worth	MKT,StL& SW,T&P.	6,000	Op.	do.	3,500	Op.	Cross.
Do.	e/Luling	SP	5,000	Op.	do.	3,750	Op.	Own.
Do.	f/Magpetco	KCSo	10,000	S.d.	do.			
Marathon Oil Co.	e/Ft. Worth	MKT,T&P	5,000	Op.	Comp.	1,500	Op.	Kellogg.
Maritime Oil Co.	f/Houston	Port Term.	4,500	Op.	S&A			
Master Pet. Co.*	e/Waco	MoP,StL&SW	800	Op.	Skim.			
McKain Refg. Co.*	e/Gladewater	None	1,500	Op.	do.			
McMurray Refg. Co.*	e/Arp	I&GN	4,000	S.d.	do.	2,000	S.d.	Own.
Mid-Texas Refg. Co.	e/Eliasville	None	*400	S.d.	do.			
Mid-West Refg. Co.*	e/Overton	I&GN	3,000	S.d.	do.			

Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
TEXAS e/ f/ (Cont'd)								
Minerva Refg. Co.*	e/Minerva	SA&AP	2,200	S.d.	Skim.			
Model Oil & Refg. Co.*	e Reeds Switch	I&GN	1,250	S.d.	do.			
Motor Fuel Products Co., Inc.	e/Laredo	I&GN, Tex. Mex.	*2,000	S.d.	do.*	*500	S.d.	Jenkins.*
Moutray Oil Co.	e/Hawley	WV	500	Op.	do.			
Muenster Refg. Co.	e/Muenster	MKT	300	Op.	do.			
National Refg. Co.*	e/Camps Switch	None	1,000	Op.	do.			
New Deal Oil & Refg. Co.*	e/Abilene	ASo, T&P	350	S.d.	do.			
Nolting Refg. Co.*	e/Sweetwater	Santa Fe	750	S.d.	do.			
Norgold Refg. Co.	e/Olney	None	210	Op.	do.			
Nueces Refg. Co.	e/Banquete	Tex. Mex.	500	Op.	Top.			
Ocean Refg. Co.*	e/Kilgore	I&GN	3,000	S.d.	Skim.			
Oil Refineries, Inc.	e/Overton	do.	4,500	Op.	do.	2,500	Op.	Own.
Olney Oil & Refg. Co.	e/Olney	WF&S	3,000	Op.	do.	1,500	Op.	Donnelly.
Omega Refg. Co.*	e/Brownwood		200	S.d.	do.			
Over Tex Refg. Co.*	e/Overton	I&GN	3,000	S.d.	do.			
Ozozo Refg. Co.	e/Friars Switch	do.	7,000	S.d.	do.			
Panama Refg. Co.*	e/Kilgore	do.	3,000	S.d.	do.			
Pan American Refg. Corp.	f/Texas City	TC Term.	25,000	Op.	do.	25,000	Op.	Kellogg.
Panhandle Refg. Co.	e/Kings Mill	Santa Fe	2,000	Op.	do.			
Do.	e/Wichita Falls	MKT	4,200	Op.	do.	1,700	Op.	Dubbs.
Pan Tex Refg. Co., Inc.	e/Coleman	None	234	Op.	do.			
Paragon Refg. Co.	e/Lueders	MKT	400	Op.	do.			
Paramount Refineries, Inc.*	e/San Angelo	Santa Fe	2,000	S.d.	do.			
Pasotex Pet. Co.	e/El Paso	MNW, NM, Santa Fe SP, T&P.	14,000	Op.	do.	4,048	Op.	Dubbs.
Pecos Refg. Co.	e/Pecos	Santa Fe, T&P.				5,000	S.d.	Jenkins.
Pelican Refg. Co.*	e/Gladewater	None	1,000	S.d.	Skim.			
Pennant Refg. Co.*	e/Kilgore	None	1,500	S.d.	do.			
Pettus Refg. Co.	e/Pettus	SP	1,000	Op.	do.			
Phillips Pet. Co.	e/Borger	RI, Santa Fe.	50,000	Op.	do.	48,000	Op.	Own.
Phoenix Refg. Co., Inc.*	e/Hawley		800	Op.	do.			
Do.*	f/Houston	MoP, SP	2,500	Op.	do.			
Do.*	e/San Antonio	MoP	600	Op.	do.			
Pilot Point Refg. Co.	e/Pilot Point	MKT, T&P	500	Op.	do.			
Pioneer Oil & Refg. Co.	e/Somerset	MoP	1,500	Op.	S&L.			

Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
TEXAS e/ f/ (Cont'd)								
Plainview Refg. Co.	e/Plainview	FW&DC	1,000	Op.	Skim.			
Pope Refg. Co.*	e/Gladewater	None	1,500	S.d.	do.			
Premier Oil Refg.Co.	e/Willow Springs	T&P	5,000	Bldg.	do.	5,000	Bldg.	Own.
Price Refg. Co.*	e/San Antonio		500	S.d.	do.			
Primrose Refg. Co.*	e/Wichita Falls	MKT	2,500	S.d.	do.			
The Pure Oil Co.	f/Nederland	KCSo.	27,000	Op.	do.	12,000	Op.	Cross.
Do.	f/ do.					3,450	Op.	Gyro.
Rado Refg. & Prod. Co.	e/McAllen	MoP	500	Op.	Skim.			
Republic Oil Refg. Co.	f/Texas City	TC Term.	6,000	Op.	do.	4,000	Op.	Winkler-Koch.
Richardson Refg.Co.*	e/Big Spring	T&P	6,000	S.d.	do.	4,400	S.d.	Jenkins.
Roco Refg. Co.*	e/Kilgore	I&GN	2,000	S.d.	do.			
J. Howard Samuell Refy.	e/Coleman	Santa Fe	100	Bldg.	do.			
S. & E. Refg. Co.*	e/Omega		200	S.d.	do.			
Shamrock Oil & Gas Co.	e/Lefors	FW&DC	1,200	Op.	do.			
Do.	e/Sunray	RI	2,000	Op.	do.			
Shell Pet. Corp.	f/Houston	Port Term.	42,000	Op.	do.	21,000	Op.	Dubbs.
Simms Oil Co.	e/W. Dallas	Santa Fe, T&P.	4,000	S.d.	do.	3,000	S.d.	Cross.
Sinclair Refg. Co.	e/El Paso	SP,T&P	2,000	Op.	do.			
Do.	e/Ft. Worth	FW&DC,RI	4,000	Op.	do.	3,000	Op.	Own.
Do.	e/Gladewater	T&P	2,500	Op.	do.			
Do.	f/Houston	Port Term. SP.	44,000	Op.	S&L	44,000	Op.	Own.
Do.	f/ do.					2,000	S.d.	Do.
Southland Refg. Co.	e/Olney	WF&S, Frisco.	650	S.d.	Skim.			
Southport Refg. Co.*	e/Kilgore	I&GN	4,000	Op.	do.	2,000	Op.	Own.
Stag Refg. Co.*	e/ do.	do.	1,200	S.d.	do.			
Star Light Refg. Co., Inc.	e/Hatchel	None	300	Op.	do.			
Star Refg. & Prod. Co.	e/Ft. Worth	Frisco	1,000	Op.	do.			
Stephenson-Hickman, Inc.*	e/Floresville	None	40	S.d.	Lube.			
Stone Oil Co.	f/Texas City	TC Term.	7,500	Op.	Skim.	2,500	S.d.	Jenkins.
Superior Refg. Co.*	e/Tiffin	T&P	700	S.d.	S&L			
Supreme Refg. Co.*	e/Gladewater	None	1,200	S.d.	Skim.			
J. J. & M. Taxman Refg. Co.	e/Wichita Falls	MKT,FW&DC, WF&S.	3,500	S.d.	do.	*1,500	S.d.	Donnelly.
Taylor Refg. Co.	e/Taylor	MKT,MoP	4,000	Op.	do.	1,000	Op.	Rowsey.*
The Texas Co.	e/Amarillo	FW&DC	4,000	Op.	do.	1,200	Op.	de Florez.

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Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
TEXAS e/ f/ (Cont'd)								
The Texas Co.	e/Amarillo					1,200	Op.	Own.
Do.	e/El Paso	SP	1,500	Op.	Skim.	1,500	Op.	Holmes-Manley.
Do.	f/Houston	Port Term. SP.	20,000	Op.	do.	1,000	Op.	Tube and Tank.
Do.	f/Port Arthur	KCSo,SP	75,000	Op.	Comp.	2,000	Op.	de Florez.
Do.	f/ do.					90,000	Op.	Holmes-Manley.
Do.	f/ do.					3,600	Op.	Own.
Do.	f/Port Neches	KCSo	20,000	Op.	Asph.			
Do.	e/San Antonio	MKT,SP	4,000	Op.	Skim.	4,000	Op.	Holmes-Manly.
Do.	e/West Dallas	Santa Fe, T&P.	16,000	Op.	do.	2,000	Op.	de Florez.
Do.	e/ do.					3,600	Op.	Holmes-Manley.
Do.	e/ do.					3,600	Op.	Own.
Texas Oil Products Co.	e/Gladewater	T&P	3,500	Op.	Skim.	1,500	Op.	Do.
Texas Pacific Coal & Oil Co.	e/Caddo	WF&S	1,000	Op.	Top.			
Do.	e/Ft. Worth	StL&SW	3,000	Op.	S&L	700	Op.	Cross.
Tonkawa Pet. Corp.*	e/Pyote	T&P	1,200	S.d.	Skim.			
Triangle Refg. Co.*	e/Kilgore	None	3,000	S.d.	do.			
Trio Refg. Corp.	e/Arp	HGN	2,000	S.d.	do.	2,000	S.d.	Own.
Tucker Oil Co.	e/Burkburnett	None	250	Op.	do.			
Tucon Refg. Co.*	e/Gladewater	None	1,000	S.d.	do.			
Tyler, Texas Prod. & Refg. Co.*	e/Tyler	StL&SW	15,000	S.d.	do.	6,000	S.d.	Own.
Tyreco Refg. Co. #1*	e/Arp	I&GN	2,500	Op.	do.			
Do. #2*	e/Overton	I&GN	3,000	Op.	do.	3,000	Op.	Own.
Union Refg. Co.*	e/Camps Switch	T&P	3,000	S.d.	do.			
Upshur Refg. Co.*	e/Gladewater	None	1,000	S.d.	do.			
Utah Refg. Co., Inc.	e/Kilgore	I&GN	*2,000	Op.	do.			
Wabash Refg. Co.*	e/Gladewater	None	1,000	S.d.	do.			
Waggoner Refg. Co., Inc.	e/Electra	FW&DC	3,500	Op.	do.			
West Texas Refg. Co.	e/Pecos	Santa Fe, T&P.	5,000	S.d.	do.	*5,000	S.d.	Donnelly.*
Wickett Refg. Co.	e/Wickett	T&P	2,500	Op.	do.			
Wolfe Refg. Co.*	e/Kilgore	I&GN	1,000	S.d.	do.			
Will C. Young Refg. Co.*	e/Archer City	None	250	S.d.	do.			
Yuba Oil Co.	e/Nacogdoches	SP	150	S.d.	Lube.			
			1,106,299			573,348		

Company	Location	Railroads	Straight distillation			Cracking		
			Cap.	Status	Type	Cap.	Status	Type
UTAH i/								
Diamond Oil Co.	Virgin	None	200	S.d.	Skim.			
Intermountain Refg. Co.	Ogden	D&RGW, UP	200	Bldg.	do.			
Carl Sealander*	do.	D&RGW, OSL	1,000	S.d.	do.	1,000	S.d.	Own.
Utah Oil Refg. Co.	Salt Lake City	BE, OSL	6,000	Op.	Comp.	6,400	Op.	Holmes-Manley.
Utah Parks Pet. Co.*	Virgin	None	100	S.d.	Skim.			
Wasatch Oil Refg. Co.*	Woods Cross	UP, D&RGW	1,500	Op.	do.	1,000	Op.	Foster-Wheeler.
Do.	do.					1,000	Op.	Vapor phase.
			9,000			9,400		
VIRGINIA a/								
The Texas Co.	Norfolk	N&PB	2,000	Op.	Asph.			
			2,000					
WEST VIRGINIA b/								
Carbide & Carbon Chemicals Corp.	S. Charleston	C&O	2,000	Op.	Skim.	1,000	Op.	Gyro.
Elk Refg. Co.	Falling Rock	B&O	2,500	Op.	Comp.			
Ohio Valley Refg. Co.	St. Marys	do.	2,000	Op.	do.	750	Op.	Dubbs.
The Pure Oil Co.	Cabin Creek Jct.	C&O	3,500	Op.	do.	750	Op.	Gyro.
Standard Oil Co. of N. J.	Parkersburg	B&O	6,000	Op.	do.	13,714	Op.	Tube and Tank.
Tri-State Refg. Co.	Kenova	C&O, N&W	*2,500	S.d.	Skim.	1,800	Op.	Jenkins.
			18,500			18,014		
WYOMING i/								
Beck Refinery	Cody	CB&Q	500	S.d.	Asph.			
G. F. Bock & Son	Clay Spur	do.	92	S.d.	Skim.			
California Pet. Corp. (Utah).	Calpet	None	300	S.d.	do.			
C. & H. Refinery	Lusk	None	75	Op.	do.			
Capitol Oil & Refg. Co.	Cheyenne	UP	250	Op.	do.			
Consumers Oil & Refg. Co.*	Newcastle	None	100	Op.	do.			
Continental Oil Co.	Glenrock	CB&Q, C&NW	2,500	Op.	do.	1,800	Op.	Cross.
Crane Refinery*	Moorcroft	CB&Q	50	Op.	do.			
Crook County Refy.	Sundance	None	50	Op.	do.			
Eclipse Oil & Refg. Co.	Newcastle	None	270	Op.	do.			
Elk Horn Gas Refy.	Osage	None	50	Op.	do.			

Company	Location	Railroads	Straight distillation Cap.	Status	Type	Cracking Cap.	Status	Type
WYOMING 1/(Cont'd)								
The Fern Oil Co.*	Thermopolis	CB&Q	500	Op.	S&A			
Gillette Refg. Co.	Gillette	do.	150	Op.	Skim.			
Golden Eagle Refg. Co.*	Casper	None	200	S.d.	do.			
Goshen Oil & Refg. Co.*	Torrington	CB&Q	250	S.d.	do.			
Gray Refg. Co.*	Newcastle	None	90	Op.	do.			
Groner Refinery*	Sheridan	CB&Q	50	Op.	do.			
Huber Refinery*	Casper	None	200	S.d.	do.			
Do.*	Riverton	None	50	Op.	do.			
Mountain Refg. Co.*	Kemmerer		500	S.d.	do.			
Northwestern Pet.Co.	Osage	CB&Q	300	S.d.	do.			
Creana Refg. Co.	La Barge	None	100	Op.	do.			
Osage Refg. Co.	Osage	CB&Q	700	S.d.	do.	750	S.d.	Cross.
Pedro Refinery	Newcastle	do.	150	Op.	do.			
Pilot Butte Refg. Co.*	Morton	None	35	S.d.	Top.			
Jack Ralston*	Upton		25	Op.	Skim.			
Red Butte Refinrey	Red Butte	None	60	Op.	do.			
Resolute Oil Corp.	Badger Basin	None	400	Op.	do.			
Salt Creek Refg.Co.*	Columbine	N&S	100	S.d.	do.			
Sheridan Refg. Co.	Sheridan	CB&Q	300	Op.	do.			
C. J. Siggins*	Cody	do.	22	Op.	do.			
Silvertop Refinery*	Hawk Springs		50	Op.	do.			
Sinclair Refg. Co.	Parco	OP	8,000	Op.	S&L	4,000	Op.	Dubbs.
Standard Oil Co. (Ind.)	Casper	CB&Q, C&NW	12,600	Op.	Comp.	6,550	Op.	Vapor phase.
Do.	Greybull	CB&Q	5,000	Op.	S&A	2,500	Op.	Cross.
Star Refinery*	Osage	do.	130	S.d.	Skim.			
The Texas Co.	Casper	CB&Q, C&NW	7,000	Op.	do.	5,000	Op.	Holmes-Manley.
Do.	do.					1,800	Op.	Own.
Do.	Cody	CB&Q	3,000	Op.	Skim.	1,500	S.d.	Holmes-Manley.
Upton Refinery	Upton	None	50	Op.	do.			
Wheatland Refg. Co.	Wheatland	None	50	S.d.	do.			
White Eagle Refg.Co.	Casper	CB&Q, C&NW	5,000	Op.	do.	2,500	Op.	Own.
Williams Refinery*	San Pedro		50	S.d.	Lube.			
Wyoco Refinery	Powell	None	40	Op.	Skim.			
Wyoil Refg. Co.	Mills	None	150	S.d.	do.			
Wyoming Gas & Oil Co.	Osage	CB&Q	150	Op.	do.			
Yale Oil Corp.*	Worland	do.	500	S.d.	do.			
			50,189			26,400		

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September 1935

DEPARTMENT OF THE INTERIOR

UNITED STATES BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

MINING METHODS AND COSTS AT THE EUREKA STANDARD MINE

BY

E. D. GARDNER

I.C. 6851
September 1935

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

MINING METHODS AND COSTS AT THE EUREKA STANDARD MINE[1]

By E. D. Gardner[2]

INTRODUCTION

The mine of the Eureka Standard Consolidated Mining Co. is at Dividend, Utah, in the Tintic mining district. It is operated under the same management and controlled by the Tintic Standard Mining Co.; the two properties adjoin each other.

The Eureka Standard is worked through a vertical shaft; the ore is mined by a stringer-set-and-fill method. One hundred and thirty men were employed in April 1933. The normal daily tonnage is 100 tons; the ore is shipped to the smelter at Garfield, Utah.

ACKNOWLEDGMENTS

James W. Wade, general manager, and the staff of the Eureka Standard Consolidated Mining Co. supplied the information from which this paper was written.

GEOLOGY

The main ore bodies in the Tintic district occur in limestone. The ore at the Eureka Standard, however, is in quartzite, which before development of the mine was not considered ore-bearing. The quartzite is overlain with shale and is lower geologically than the limestone in the district. The vein is a fault fissure in the quartzite near the contact with the shale.

In places faulting action has dropped the shale to form the hanging wall of the vein, which requires immediate support; moreover, the nearness of the shale elsewhere over the orebodies makes the hanging wall heavy.

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U.S. Bureau of Mines Information Circular 6851."

2 Supervising engineer, U.S. Bureau of Mines Southwest Experiment Station, Tucson, Ariz.

The vein dips from 45° to 60°; the average dip is 55°. The average thickness of the ore in the main vein is 5 feet; the ore feathers out at the edges of the shoots.

The vein matter is fractured quartzite. The principal gold-bearing minerals are tetrahedrite and enargite associated with bornite and pyrite. Argentite occurs in the high-grade streaks; hessite and calaverite are found occasionally. Galena is a minor accessory mineral in parts of the mine.

The permanent water level in the mine is 1,314 feet below the collar of the shaft; this horizon corresponds roughly with the level of Utah Lake 10 miles distant. The temperature of the mine water ranges from 80° to 125° F.

The method of sampling and estimating ore tonnages is the same as that at the Tintic Standard mine.3/

HISTORY

After a study of the geology of the surface and of the formation as disclosed in a crosscut from the Tintic Standard mine a shaft was begun in 1924. Ore was struck in June 1928 and the 1,100 level. Production was started on a 50-ton-per-day basis and later brought up to 3,000 per month. The first ore mined was hoisted in the Tintic Standard shaft. The production of ore and metals to the end of 1932 is shown in table 1.

In 1929 the shaft was extended to the 1,300 level and a crosscut run to the vein. By March 1, 1930 a new hoist, steel headframe, compressor, changehouse, ore bin, conveying equipment, and railroad spur were completed. All of the development work done and equipment purchased after shipments began was paid from the company's earnings.

In 1930 the gross proceeds from all metals were $793,412; after smelting and freight charges of $201,987 were paid, the net smelter returns amounted to $591,425. After $296,072 was deducted for miscellaneous expenses, including $12,612 for taxes, the net profit carried to surplus account was $297,091. The initial dividend of $44,987.70 was paid in September 1930; the second of the same amount was paid in December. The mine ranked second as a producer of gold and eleventh as a producer of silver in Utah in 1930. In 1931 it ranked fifth as a producer of silver.

In 1931 gross proceeds of all metals were $1,186,516; after freight and smelting charges of $260,902 were deducted, net smelter returns were $925,614. The total income was $929,775. After expenses of $453,373, including depreciation and taxes were paid, a net profit of $476,402 was carried to surplus account. Dividends of $179,951 were paid in 1931.

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3 Wade, James W., Mining Methods and Costs at Tintic Standard mine, Tintic District, Utah: Inf. Circ. 6360, Bureau of Mines, October 1930, 21 pp.

TABLE 1. - Production at Eureka Standard mine

Year	Production				
	Tons	Gold, ounces	Silver, ounces	Copper, pounds	Lead, pounds
1928 ..	4,296	3,284.75	45,440	13,789	49,931
1929 ..	18,363	14,755.42	193,098	68,360	191,981
1930 ..	28,459	30,540.37	295,169	208,737	567,950
1931 ..	36,622	48,206.57	452,251	293,969	886,337
1932 ..	36,294.38	39,274	337,251	345,083	842,189

In 1932 the ore had a gross sale value of $950,570, and after all charges were deducted the net profit for the year was $232,703. During the year the property was the fifth largest lode gold mine in the United States.

SURFACE EQUIPMENT

The equipment at the surface was used principally in connection with hoisting and air compression.

Drill steel was sharpened and minor repairs of equipment were made in a blacksmith shop near the shaft. All major repairs were made and electrical and machine work performed in the Tintic Standard shops.

In May 1933 the equipment consisted of an 85-foot steel headframe, a double-drum hoist with $3\frac{1}{2}$- by $4\frac{1}{2}$-foot drums and run by a 200-hp. induction motor; an air compressor with a capacity of 2,690 cubic feet of free air per minute under 100 pounds pressure per square inch; a transformer, switchboards, and other electrical equipment in connection with hoisting and air compression; a 34-inch belt conveyor 75 feet long with an apron feeder; a 150-ton steel ore bin; a drill sharpener and oil heating furnaces; and a two-man blacksmith shop.

No living quarters or general offices were maintained at the mine. The workmen and the supervisory force were carried to and from Dividend, 1 1/2 miles distant, in busses or rode to work in private cars. The buildings at the mine consisted of a steel and corrugated-iron structure 25 by 63 feet over the hoist and compressor, a 30- by 50- foot changehouse, a 20- by 30-foot blacksmith shop, a 12- by 20-foot mine office and storeroom, and a two-room foreman's cottage.

The following table shows the expense of equipping the mine, both above and below ground, up to December 31, 1932.

Assets as of December 31, 1932

Buildings and headframe	$67,300.03
Machinery	61,107.00
Electrical equipment	39,792.98
Other equipment	123,717.18
Water system	7,482.04
Furnishing and fixtures	109.00
Total	299,508.23

METHODS OF DEVELOPMENT

The mine is developed and worked through a five-compartment shaft 1,424 feet deep. Levels are run at 800, 900, 1,000, 1,100, and 1,300 feet from the surface. In addition, two sublevels have been driven below the 1,300-foot drift; the first is 500 feet long from a 50-foot winze and the second 400 feet long at the 1,400 level. Disregarding sublevels between the upper levels, 6,600 feet of drifting has been done on the vein.

The mine is connected with the Tintic Standard on the 800 level and to the Iron King No. 2 shaft on the 1,300 level.

The vein is prospected and the ore developed by raises at 100-foot intervals. If justified by geological evidence or needed for mining purposes, other raises are run midway between the first series.

The vein is prospected further by driving sublevels at strategic points between the main levels ahead of stoping. Prospecting crosscuts are run into the hanging wall at geologically favorable places and where needed for waste filling.

Shaft

The shaft is 5 feet 11 1/2 inches by 22 feet outside of the 8- by 8-inch timbers; it is divided into two 4-foot 1-inch by 4-foot 8-inch hoisting compartments, one 8-foot 4-inch by 4-foot 8-inch ventilation and pump compartment, and a 2-foot 6-inch by 4-foot 8-inch ladder and cableway.

Drifts and Crosscuts

The main haulageways are 6 by 9 feet in section; drifts on the vein are run 5 by 7 feet in size. Drift rounds in the smaller headings consist of 11 to 13 holes about 4 feet deep. An average round consists of 3 downward toe-cut holes, 2 relievers, 3 back holes, and 3 lifters. Development rounds are blasted with 40-percent-strength gelatin dynamite. A cycle is made in a drift face each shift; the broken rock from the previous round is loaded out while the round is being drilled. The round is blasted at the end of the shift.

A mechanical loader is used in the 6- by 9-foot headings. A round consisting of seventeen 0.9-ton cars is loaded out in 3 hours; one man operates the machine and another trams the cars in and out. Where a plentiful supply of broken rock exists and the loader can be kept steadily supplied with cars 27 tons can be loaded in 1 hour.

One and one quarter inch round steel is used with drifters; 1-inch quarter octagon in stopers, and 7/8-inch hexagon in jackhammers. A driller uses one or more 3-piece sets of steel in drifts and raises and one or more sets in stopes.

Raises

Raises are 12 feet by the width of the vein in section. Raise rounds consist of 8 to 16 holes; the average distance broken per round is a little less than 3 feet.

STOPING

As stated before, the ore is developed by drifts about 120 feet apart vertically and raises from the drifts on 50-or 100-foot centers. Preparatory to mining, the prospect raises are widened to three sets; they are then used for ore chutes and manways and for bringing waste filling into stopes. Stopes between the 1,300 and 1,100 levels when completed are 27 floors high; sublevels from raises are run at various intervals for bringing in waste filling and for access to the stopes.

A cross-section of a typical Eureka Standard stope is shown in figure 1. The drift is timbered with stringer sets 6 feet center to center. The caps or stringers are of 8- by 8-inch timber about 10 feet long. The ends of the caps are blocked against the solid. The posts are of 10-inch round timber and are 8 feet long; they rest on 8- by 8-inch sills blocked into place. Split round poles are used for collar bracing. Scabbing nailed on the caps and sills prevents lateral movement.

After the drift timbering is in, stoping begins. The first rounds are drilled from small stagings set up in the drift. Hand-rotated stopers are used. The first ore is broken on lagging platforms and shoveled into cars. As the stope rises ore chutes are installed, and the ore is drawn directly into cars.

As stoping operations continue, timbering is put in place as shown in the section. The sets are 6 feet center to center both horizontally and vertically. Posts are placed directly over one another if possible, or they are placed directly over a block on the footwall, thus carrying the weight vertically downward. For loose or heavy ground small stulls or back lagging can be utilized as illustrated.

After a section is mined up to the next level or sublevel, preparations are made for filling the stope. If the face on either side of the section indicates continuation of the ore, it is laced off with vertical lagging 6 feet long. However, it is rarely necessary to fill before the ore is completely

mined out. The caps on the sill floor are then relieved of their scabs, and the posts are chopped out if necessary. Two 10 by 10 squeeze blocks are then placed over the sill floor posts as illustrated, then a 10 by 10 is placed on these blocks and wedged tight with blocks and wedges. Round poles are then placed longitudinally over the 10 by 10 caps. The number of round poles varies with the width of the fissure, the number usually running about three to a horizontal distance of 6 to 7 feet. The round poles are covered with a layer of new lagging and a layer of used lagging on which is placed cribbing made of old pieces of timber. The cribbing is intended to take the shock of falling rock when the stope is first being filled. Filling for the stope is obtained from waste drifts run for that purpose or from exploration drifts at geologically favorable places. Waste occuring in the ore is sorted out and placed in the gob.

All timber is left in place during the filling operations; the only timber saved is the flooring (lagging used between stringers for a working floor).

From 6 to 8 places are worked at the same time, although 15 to 20 places usually are opened up ready for working. A stope crew consists of a drill runner and a shoveler. Usually only one section in a stope is worked at one time. The drill runner and shoveler do their own timbering as a rule. Timber crews consisting of a timberman and a helper work on special jobs, such as building chutes, repairing broken timbers, or timbering exceptionally heavy stopes.

Stoping and raising are done with hand-rotated wet stopers; 10 of these machines are in daily use. Six jackhammers are used for block holing in stopes and for other miscellaneous work in the mine.

A stope round consists of 6 or 7 holes each loaded with 1 or 2 cartridges of 25-percent strength gelatin dynamite. A mine rule limits the charge to two sticks per hole. An average of 15 cars or 13 1/2 tons is broken per round. A ton of ore occupies 12 cubic feet in the solid and 20 cubic feet when broken.

HOISTING

The ore and waste are hoisted in 40-cubic-foot self-dumping skips; men and material are handled on cages. Hoisting may be done in 2 skips running in balance or in 1 skip running in balance with a cage. Cages are used in both hoisting compartments for lowering and hoisting the shift. Skips or cages when not in use are set on trucks 10 feet long standing on tracks at the collar of the shaft. To change from a skip to a cage an empty truck is run over the compartment on a sectional track and the skip is lowered and detached from the hoisting cable. The cage on the truck is then pushed into place and attached to the cable. A transfer is made in 10 minutes.

The skips are dumped in 1 of 2 hoppers; waste is run to a dump. The ore is transferred by the belt conveyor to the ore bins where it is loaded into 70-ton cars for shipment to the smelter. When nothing interferes with the work, 12 skips can be hoisted per hour.

Waste is hoisted in cars for filling; 100 cars can be handled in 8 hours from the 1,300 to 1,100 levels. The cages are single-decked and hold 1 car each.

Long timbers and other heavy material are raised for loading on the cage by means of a scraper hoist set near the collar of the shaft. The sheave is attached above the shaft compartment to the first steel member of the headframe. The bonnet of the cage is raised and the material lowered into place.

The hoist that was used in sinking the shaft is used for running a "chippy" cage in the pump compartment; this cage is employed by men working in the shaft.

Two men, a cage rider and a station tender, load skips and handle waste cars and supplies on the cages. Two top carmen on day and one on night shift handle waste and do other work at the surface in connection with hoisting.

UNDERGROUND HAULAGE

A storage-battery locomotive is used for tramming underground on the main levels. It is transferred from level to level on the cage and brought to the surface for changing batteries. One battery is used on day shift and one on night shift. Two batteries have been in use for 3 years and have required no repairs. The locomotive can pull fourteen 0.9-ton cars; an average train is 10 to 12 cars. Ore is moved to the station by hand on sublevels.

Track gage is 18 inches; most of the track consists of 12-pound rails set on steel ties on 4- to 5-foot centers.

Eighteen-cubic-foot end-dump cars are used. A turntable under the body permits the cars to be discharged at the end or either side. The ore is dumped at the stations on grizzlies with 8-inch spaces between the bars. A relatively small amount of material must be broken by hammers to pass through the grizzlies.

Ore chutes are built between sets. The bottom consists of three 12-inch planks. The chute opening is 2 feet 4 inches wide. Board gates are used.

The haulage crew consists of a motorman and a helper. In addition to pulling the ore trains to the shaft, this crew hauls waste to the shaft on the 1,300-foot level and pulls it to the waste raises on the 1,100 level. Two men tram and dump waste cars.

PUMPING

Practically all the water comes from the sublevels below the 1,300. The water is raised through 6-inch pipe to the 1,300 level and thence runs by gravity through a 14-inch-diameter 10-gage pipe to the 1,300 station sump which has a capacity of 17,600 gallons.

From the 1,300 level the water is raised directly to the surface by a 1,000-gallon-per-minute pump and by two 600-gallon-per-minute pumps in series. One of the 600-gallon pumps is on the 1,300 and the other on the 800 level. Two lines of 6-inch and one line of 12-inch pipe are used in the shaft.

The pumping equipment is as follows:

3 no. 3 R. V. Cameron pumps with a capacity of 400 gallons per minute each, under a 110-foot head and run by 15-hp., 65-volt motors; in sublevel.

3 no. 4 R. V. Cameron pumps with a capacity of 800 gallons per minute each, under a head of 100 feet, and run by 25-hp., 110-volt motors; in sublevel.

2 no. 5 H. M. T. Cameron station pumps on 1,300 level discharging at surface, with a capacity of 1,000 gallons per minute, run by 500-hp., 2,300-volt motors.

2 no. 4 H. S. T. Cameron station pumps on 1,300 level discharging on 800 level, with a capacity of 600 gallons per minute, run by 200-hp., 2,300-volt motors.

2 no. 4 H. S. T. Cameron station pumps on the 800 level discharging at surface, with a capacity of 600 gallons per minute, run by 200-hp., 2,300-volt motors.

The 600-gallon pumps run an average of 13 hours during each 24 hours and the 1,000-gallon pumps 9 hours.

Pumping costs in January and February 1933 are shown in the following table.

Month	Power	Labor	Repairs	Total
January..........	$1,388.86	$487.08	$97.70	$1,983.66
February.........	1,631.28	405.50	50.58	2,093.36

VENTILATION

The Iron King No. 2 shaft is used as an up-cast and the main shaft as a down-cast airway. The mine is ventilated by means of a no. 12 Plexiform fan run by a 100-hp. motor on the 1,450 level of the up-cast shaft. This fan has a capacity of 76,000 cubic feet per minute at 3 1/2 inches water gage. A 6-foot Aerovane booster fan run by a 60-hp. motor is used underground to assist the surface fan. The booster has a capacity of 40,000 cubic feet at 3.2 inches pressure.

Stopes and dead-end drifts are ventilated by 22 no. 2 1/2 size blowers, mostly of the Vano and Ventair types. Six are air-driven and the others

electric. Sixteen- and eighteen-inch pipe is used in the main splits with 10-inch branches into stopes or dead-end drifts.

To keep the mine air from being humidified the water is conveyed from the pumps at the winzes to the main sump at the shaft through pipes instead of in ditches or flumes. The temperature of this water is over 100° F.

POWDER MAGAZINE

The main powder magazine holds two railroad carloads of explosive. It consists of a drift run in the mountain on the other side of a ridge and 2,000 feet from the shaft. A bulletproof door is used.

To discourage trucking explosives on the highways, the manufacturer quotes the same price f.o.b. cars at Dividend as at the plant in the Salt Lake Valley.

FIRE PROTECTION

All inflammable trash is promptly removed from the mine. Periodical inspection is made of all electrical wiring and installations underground.

A small guniting machine mounted on a mine truck is used for sealing ventilation doors and for fireproofing timber underground.

SHARPENING STEEL

The steel is sharpened near the shaft. Oil furnaces are used for heating. An average of 1,000 gallons of fuel oil at 6 cents per gallon is used monthly in the furnace. An average of 200 pieces of steel is sharpened daily. Drill steel is sharpened as an accommodation to a nearby small operator at 25 cents per bit. Only a few pieces are handled at a time.

A blacksmith and helper make miscellaneous repairs at the mine; 600 pounds of coal and 600 pounds of coke are used in the blacksmith shop monthly. Drill repairs and all heavy work are done for the company at the Tintic Standard shops.

SURFACE TRUCKING

A 1 1/2- and a 3-ton truck are used in hauling supplies to the mine; a 1 1/2-ton truck is used at the mine.

The freight rate on supplies on the regular truck line from Salt Lake City was 42 to 68 cents per 100 pounds.

LABOR

In April 1935 no bonus or contract systems were in use.

An average of 130 men was on the pay roll; of these 115 worked underground. The force actually employed in stopes on ore consisted of 11 machine miners, 11 shovelers, 6 timbermen, and 6 timbermen helpers. In addition two timber crews were employed on special repair work about the mine.

The wage scale established on March 20, 1932 and in force May 1, 1933 was as follows:

Underground

Shift bosses	$5.00	Motormen	$3.50
Shaftmen, repairs	4.25	Pipe and track men	3.50
Shaftmen helpers, repairs	4.00	Pipe- and track-men helpers	3.25
Shaftmen, sinking	4.25	Pumpmen	3.50
Shaftmen, sinking in water	4.50	Topmen, lead	3.50
Miners	3.50	Topmen	3.00
Muckers	3.00	Cagers	3.50
Timbermen	3.50	Cagers helpers	3.25
Timbermen helpers	3.25	Ventilation men	3.50
Trammers	3.00	Ventilation-men helpers	3.25

Mechanical Department

Hoisting engineer	$4.25	Machinist	$4.00
Hoisting engineer (donkey underground)	3.50	Welder	4.00
Compressormen	3.25	Tool sharpeners	4.00
Blacksmith	4.25 - 4.00	Drill-machine repairmen	4.25
Blacksmith helpers	2.75	Pipe fitter	3.25

Electrical Department

Electrician	$4.25	Electrician helper	$3.75

Truck Department

Mechanic	$4.75	Truck-driver helpers	$2.75
Truck driver	3.25		

Carpenter Shop and General Surface

Carpenters	$4.25	Timber-framer helpers	$2.75
Carpenter helpers	3.00	Laborers	2.75
Brick mason	3.75	Watchman	3.25
Teamster	3.50 - 3.25	Powderman	3.25
Timber framer	3.00		

Assay Office

Assistant assayer	$3.50	Assay helpers	$2.75
Assay helpers	3.00	Sample buckers	2.75

Two increases in pay were granted in September 1933, and the force was put on a 5-day week. Miners received $4.75 and muckers $4.25 after these increases; other classifications were increased accordingly.

Prior to this change the mines in the district were operated 7 days per week. The length of a shift is 8 hours.

SMELTING

The ore is desired by the Garfield smelter for its silica content in smelting copper concentrates. The gangue is principally quartzite.

The distance to the smelter is 120 miles. The freight rate is as follows:

Value of ore, dollars	Freight per ton
Up to 6	$0.75
6 to 8	.90
8 to 10	1.00
10 to 15	1.10
15 to 20	1.25

Above $20 the freight rate increases $0.25 per ton for each $10 increase in value of the ore.

The base smelting rate is $3 per ton. Where the gross value of the ore is over $10 per ton, the sampling rate is $0.35; under $10 the rate is $0.50 per ton.

The smelting contract provided for the payment of the metals according to the following schedule:

Metal	Proportion on which payment was made, percent	Price paid
Gold	100	$20 per ounce
Silver	95	New York quotation
Lead	50	market, minus $0.0352 per pound
Copper	70	market, minus $0.0202 per pound

The copper content of ore is about 1 percent.

The free market for gold has been established since the smelter contract was made. The smelter continues to pay for the gold in the ore on receipt at $20 per ounce as received. The difference between $20.67 and the price received by the smelting company, minus a percentage for smelter losses, minus 1 1/2 percent handling charges, is paid to the mining company as of the date of sale of the gold.

COSTS

Table 2 gives a summary of mining costs in February 1933, not including administration or taxes. Comparative costs in January and February 1933 of labor, material, and power are contained in table 3 and segregated labor costs in table 4. Table 5 shows the labor and explosive cost for different kinds of development work in 1932. The total cost of sinking the shaft and running the 1,100 and 1,300 levels to the end of 1932, as calculated for the purpose of capitalizing the development work, is shown in table 6. Table 7 gives the total cost of development as capitalized and table 8 the fixed assets as of September 30, 1931.

TABLE 2. - Costs per ton of ore hoisted, February 1933 1/
(3,737.0 tons)

	Labor	Explosives	Timber	Power	Supplies	Total
Development......	2/$0.96	(3/)	....	....	....	$0.96
Stoping..........	2/ 1.52	(3/)	4/$0.51	....	5/$0.62	2.65
Hoisting.........	.16	0	0	$0.33	....	.49
Tramming.........	.17	0	0	....	....	.17
Air compression..	.05	0	0	.31	....	.36
Pumping..........	.11	0	0	.43	....	6/ .54
Maintenance and filling........	.22	0	....	....	....	.22
General and surface...........	1.55	....	....	7/ .46	....	2.01
Total.......	8/4.39	$0.35	0.51	1.53	0.62	7.40

1 - Does not include administration or taxes.
2 - Includes explosives.
3 - Explosive for development and stoping, $0.35 per ton of ore
4 - Includes timber used in development.
5 - All departments of the mine.
6 - Does not include new pipe line on 1,300-foot level; cost $477.00.
7 - Principally ventilation.
8 - $0.35 per ton for explosives subtracted.

TABLE 3. - Costs per ton of ore hoisted, January and February 1933 1/

Month	Dry tons	Labor	Material	Power	Total
January..........	3,886.9	$4.798	$1.777	$1.339	$7.914
February.........	3,737.0	4.391	1.484	1.534	7.409

1 - Does not include administration or taxes.

NOTE: Power and supplies prices: Power, average, 1 cent per kw.-hr.; explosives (40 percent gelatin dynamite) $12.50 per 100 pounds; timber, sawn, $28 to $30 per 1,000 feet, and round, average 8-inch diameter, 11 cents per linear foot.

TABLE 4. - Segregated labor costs, January and February 1933

Month	Miners	Timbermen	Muckers	General direct labor	Indirect labor	1/ Shops	Total	Costs per ton
January....	$2,086.04	$2,251.95	$2,471.67	$2,290.00	$5,110.62	$3,482.66	$17,692.94	$4.55
February...	2,301.41	2,045.02	2,584.56	1,851.00	4,178.29	3,447.17	16,407.95	4.39

1 - Work done for Eureka Standard by Tintic Standard; shop work, assaying, etc.

TABLE 5. - Development costs, 1932; labor and explosives only

	Direct labor1/	Explosive	Total	Footage	Cost per foot
Drifts and crosscuts..	$10,801.13	$3,749.81	$14,550.94	2,301	$6.323
Drifts from winze.....	10,971.55	1,705.19	12,676.74	624	20.315
Raises................	4,947.44	834.85	5,782.29	441	13.111
Main winze............	8,533.62	393.33	8,926.95	184	48.516
Other winzes..........	1,399.13	150.63	1,549.76	84	18.449
Total...........	36,652.87	6,833.81	43,486.68	3,634	11.969

1 - Includes cost of placing timber where needed in development work.

TABLE 6. - Cost of development work 1924-31, inclusive; 1,100 and 1,300 levels and shaft

Item	1,100 level	1,300 level	Shaft
Total footage	2,643.5	4,281.0	1,424.2
Direct expenses:			
Labor	$19,035.62	$32,329.28	$89,209.85
Material (mostly explosives)	4,752.62	8,711.22	46,873.26
Total	23,788.24	41,040.50	136,081.11
Cost per foot	9.00	9.59	95.56
Indirect expenses:			
Labor	14,819.82	23,299.29	23,544.84
Material	7,431.18	13,875.64	8,985.10
Power	4,044.82	11,668.56	9,236.10
General	3,599.44	10,193.20	7,565.71
Total	29,895.26	59,036.69	49,331.75
Cost per foot	11.31	13.78	34.64
Grand total	53,683.50	100,077.19	185,412.86
Total per foot	20.31	23.37	130.20

TABLE 7. - Total development, capitalized

Expended 1917 to end of 1927	$290,236.48
Upper levels, 1928 to September 30, 1931 (includes 722 feet of drifting and 89 feet of raises)	23,086.93
Iron King drift, 1,700 feet in length	26,280.58
Other development	57,100.06
Total development capitalized	396,704.05

TABLE 8. - Fixed assets, September 30, 1931

Development	$317,187.57
Mining property	197,043.45
Patents, lands, etc	3,875.56
Plants, equipment, and buildings (net)	176,244.82
Total fixed assets	694,315.40

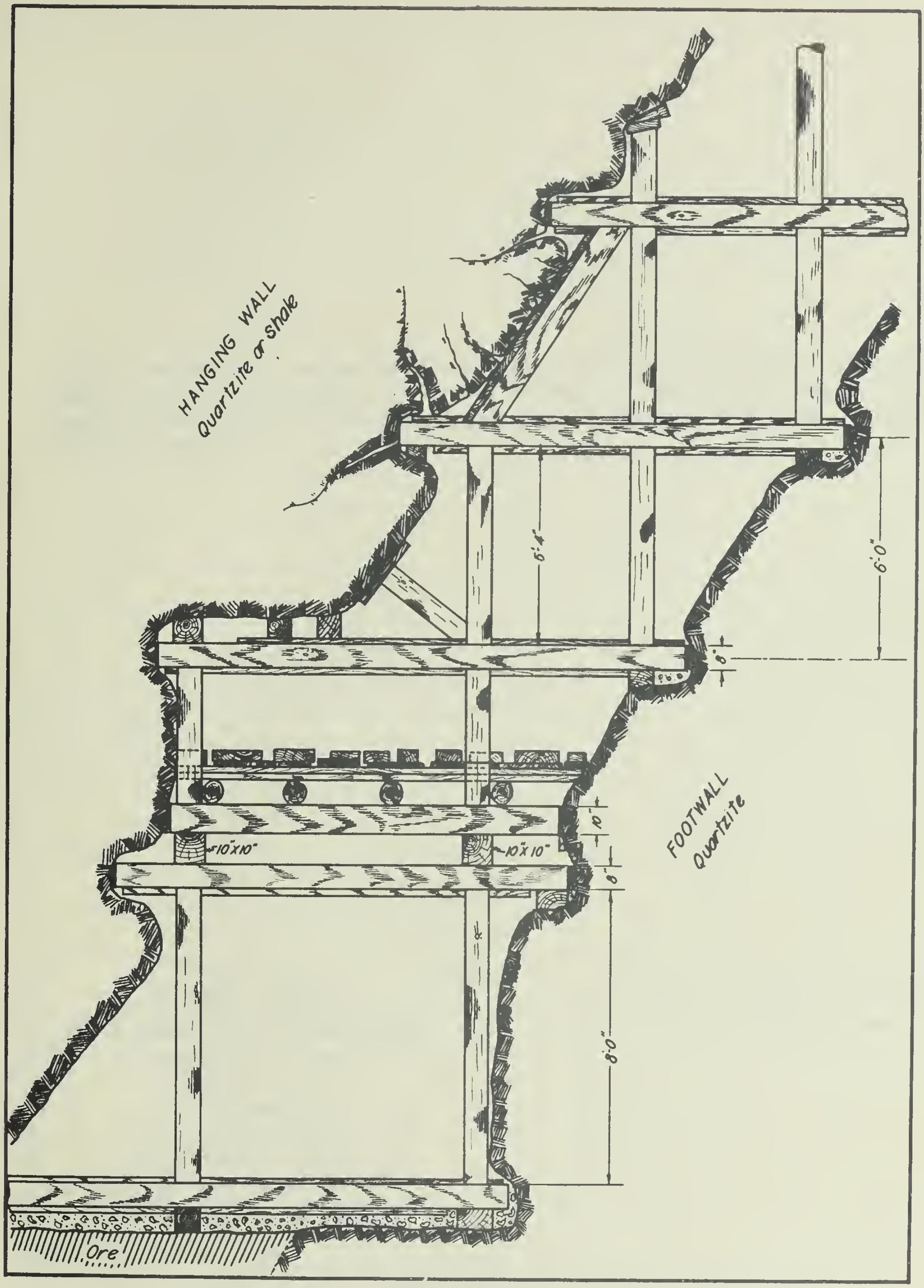

Figure 1.— Stope timbering, Eureka Standard mine.

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

QUESTIONS AND ANSWERS ON FIRST-AID TRAINING [1]

By J. J. Forbes[2] and M. J. Ankeny[3]

INTRODUCTION

Several sets of questions and answers on the fundamentals of first aid to the injured, based on the Manual of First-Aid Instruction of the United States Bureau of Mines, are now in use in various parts of the United States. Persons experienced in first-aid instruction believe that a standardized set of questions and answers will assist materially in preparing men for examinations conducted by the Bureau for first-aid certificates. Inquiries as to whether a set of standardized questions and answers is available have been made frequently by those training men for the Bureau of Mines examination for certificates.

It is believed that the following list of 171 questions and answers compiled directly from the manual will be useful to company officials and employees who are engaged in cooperative first-aid training to qualify for Bureau of Mines certificates. The list may also be used by field men of the Bureau in training instructors preparatory to a cooperative training campaign and in examining classes or individuals for first-aid certificates. The page references in parentheses refer to pages in the Manual of First-Aid Instruction.

QUESTIONS AND ANSWERS ON FIRST-AID TRAINING

Anatomy

1. Q. What proportion of the body, by weight, is composed of blood?
   A. About one thirteenth of the weight of the body is blood. (P. 15.)

2. Q. What is the skeleton?
   A. The skeleton is the framework of the body. (P. 15.)

3. Q. What is the composition of the skeleton?
   A. The skeleton is composed of a hard substance called bone. (P. 15.)

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4. Q. What is the purpose of the skeleton?
   A. The skeleton supports and carries the soft parts, protects the vital organs from injury, and gives attachment to the muscles. (P. 15.)

5. Q. Into what three parts is the body divided?
   A. The body is divided into the head, trunk, and extremities. (P. 15.)

6. Q. What is the cranium?
   A. The cranium is a bony case which encloses and protects the brain. (P. 15.)

7. Q. What divides the trunk into two parts?
   A. The trunk is divided into two parts by a muscular partition called the diaphragm. (P. 15.)

8. Q. What organs are contained in the upper portion of the trunk?
   A. The gullet, heart, lungs, and some large blood vessels. (P. 15.)

9. Q. What organs are contained in the lower portion of the trunk?
   A. The stomach, liver, kidneys, bladder, and intestines. (P. 15.)

10. Q. What are the upper and lower portions of the trunk commonly called?
    A. The upper and lower portions of the trunk are commonly called the chest and abdomen, respectively. (P. 15.)

11. Q. What bones form the trunk?
    A. The spinal column or vertebrae, ribs, pelvis, coccyx, and sternum form the trunk. (P. 17.)

12. Q. How many ribs are there?
    A. There are 24 ribs, 12 on each side. (P. 17.)

13. Q. What is the spinal column?
    A. The spinal column, made up of a number of smaller bones called vertebrae, extends from the base of the cranium to the pelvic bone and forms a standard for attachment of the ribs. (P. 17.)

14. Q. What is the function of the spinal column?
    A. Its function is to give rigidity to the body and to form a canal or protective covering for the chief nerve fibers of the body, the spinal cord. (P. 17.)

15. Q. What is the pelvic bone?
    A. The pelvic bone is a flat dish-shaped bone which gives a point of attachment for the lower extremities and supports the bladder and bowels. (P. 17.)

16. Q. What is the danger of a fractured pelvis?
A. The danger of a fractured pelvis lies not only in the broken bone but also in the fact that the bladder which lies just behind the bones that make up the front wall of the pelvis may become punctured through movement of the patient. (P. 116.)

17. Q. Of what do the extremities consist?
A. The upper extremities consist of the shoulder joint, arm, forearm, wrist, and hand; the lower extremities consist of the thigh, leg, ankle, and foot. (P. 17.)

18. Q. How many bones are in each upper extremity, and what are they?
A. Each upper extremity has 1 collar bone, 1 shoulder blade, 1 arm bone, 2 forearm bones, 8 wrist bones, 5 hand bones, and 14 finger bones. (P. 17.)

19. Q. How many bones are in each lower extremity, and what are they?
A. Each lower extremity has 1 thigh bone, 2 leg bones, 1 kneecap, 7 ankle bones, 5 foot bones, and 14 toe bones. (P. 17.)

20. Q. What is a joint?
A. Where two or more bones come together they form a joint. (P. 17.)

21. Q. How are the bones held in position at the joints?
A. The bones are held in position by bands called ligaments. (P. 17.)

22. Q. What are muscles, and what is their function?
A. Muscles give shape to the body, and by lengthening or shortening they cause movement of the parts to which they are attached. (P. 18.)

23. Q. What are tendons, and what is their function?
A. Tendons are strong, white, fibrous cords that attach most muscles to bone. (P. 18.)

24. Q. How is nourishment carried to the different parts of the body?
A. The blood carries nourishment to the different parts of the body by means of closed tubes called blood vessels. (P. 18.)

25. Q. What other function does the blood perform?
A. The blood furnishes heat and oxygen to all parts of the body and carries waste matter from all the tissues to the lungs, kidneys, skin, and bowels, whose work it is to separate the wastes from the blood and expel them from the body. (P. 18.)

26. Q. What keeps the blood stream in motion?
A. The blood is kept moving by the pumplike action of the heart. (P. 18.)

27. Q. What is the heart, and where is it located?
A. The heart is a muscular organ about the size of a man's fist, situated in the chest behind and to the left of the breastbone. (P. 18.)

28. Q. Explain the action of the heart?
A. The heart acts like a double-action pump, one side forcing the fresh blood through the body and the other side forcing the impure blood to the lungs. (P. 20.)

29. Q. What is the rate of speed at which the heart operates normally?
A. The heart contracts or beats about 72 times per minute. (P. 20.)

30. Q. What are the blood vessels?
A. The blood vessels are the arteries, veins, and capillaries through which the blood is conveyed to all parts of the body. (P. 20.)

31. Q. What is the function of the arteries?
A. The arteries carry the pure blood from the heart. They divide and subdivide until they become very small and are known as capillaries. (P. 20.)

32. Q. What is the function of the veins?
A. The capillaries join, finally forming veins through which the impure blood is returned to the heart. (P. 20.)

33. Q. Where may the pulse beat rate be examined conveniently?
A. The pulse beat can be felt at the wrist or temple. (P. 20.)

34. Q. What is meant by respiration?
A. Respiration means breathing - inhaling pure air and driving out (exhaling) the impurities that the lungs have separated from the blood. (P. 20.)

35. Q. What are the lungs?
A. The lungs are two cone-shaped bodies which are soft, spongy, and elastic. The outside of each lung is covered by a closed sac called the pleura. (P. 21.)

36. Q. How is the blood purified in the lungs?
A. The lungs contain very delicate capillaries with blood on the inside and air on the outside, so that gases in the air and blood are easily exchanged. (P. 21.)

37. Q. What is the normal rate of breathing?
A. In healthy persons breathing occurs about 15 to 20 times per minute. (P. 21.)

38. Q. What duty is performed by the nervous system?
A. The nervous system keeps the different parts of the body in touch with each other, and it controls and regulates the functions of the organs. (P. 22.)

39. Q. Of what does the nervous system consist?
A. The nervous system consists of nerves and nerve cells or centers. (P. 22.)

40. Q. Describe the nerves?
    A. The nerves are round, white cords consisting of nerve fibers which form connections between the nerve centers and the ends of the nerves. (P. 22.)

41. Q. Why does the nervous system play an important part in injuries?
    A. The nerve centers are always affected by serious injury and a condition of shock generally results. (P. 22.)

Shock

42. Q. What is shock?
    A. Shock is a sudden vital depression of the nervous system. (P. 23.)

43. Q. What causes shock?
    A. Severe pain, loss of blood, fright, anger, surgical operations, seeing one's own injury or injuries of others, and accidents by electricity or gas may cause shock. (P. 23.)

44. Q. What are the symptoms of shock? (P. 23.)
    A. 1. The face is pale and has an anxious expression.
       2. The eyelids droop, the eyes are dull, and the pupils large.
       3. The skin is clammy and covered with cold sweat.
       4. The patient is somewhat stupid and takes little interest in things about him.
       5. He may suffer from nausea and vomiting.
       6. He may answer questions slowly.
       7. He may be partly or totally unconscious.
       8. Breathing is shallow and feeble.
       9. The pulse (heart action) is rapid and weak and may not be felt at the wrist.

45. Q. What is the treatment for shock? (P. 23.)
    A. 1. Place the person in a comfortable position with head low.
       2. Remove all foreign substances from the mouth.
       3. Wrap him in warm blankets, clothing, or brattice cloth.
       4. Give a liquid stimulant if patient is conscious.
       5. Allow patient to inhale fumes of aromatic spirits of ammonia if he is unconscious. First-aid man should test strength of stimulant before applying.
       6. Place heat applications around patient under covering.
       7. Rub legs and arms toward body under covering.
       8. Place a small heat application over heart.

46. Q. Under what conditions would it be improper to place the patient's head low?
    A. When there is a fractured skull or severe hemorrhage from the head, also in cases of sunstroke and apoplexy. (P. 23.)

47. Q. Under what conditions would it be improper to give a stimulant to a patient who is suffering from shock?
    A. If the person has a fractured skull, sunstroke, apoplexy, or severe bleeding from the head, do not give a stimulant. If the patient has internal bleeding or arterial bleeding, do not give a stimulant until the hemorrhage has been checked. (P. 23.)

48. Q. What may be used for heat applications?
    A. Heat pads, hot-water bottles, hot bricks, stones, etc., may be used for heat applications. (P. 24.)

49. Q. What precaution must be taken with heat applications to avoid burning patient?
    A. Wrap heat applications in cloth or paper and test before applying. (P. 24.)

50. Q. What substance or material may be used for a liquid stimulant?
    A. Aromatic spirits of ammonia (a teaspoonful in a half glass of water), hot coffee, hot tea, or hot water. (P. 24.)

51. Q. How should a liquid stimulant be administered?
    A. Raise person's head and allow him to take liquid in sips from a glass. (P. 24.)

52. Q. Under what condition should a liquid stimulant be given?
    A. A liquid stimulant should be given when the patient is conscious. (P. 24.)

53. Q. How may stimulant be given if patient is unconscious?
    A. Give stimulant to an unconscious person by pouring aromatic spirits of ammonia on a cloth and permitting the patient to inhale the ammonia fumes. The strength of the fumes should be tested before they are applied to the patient. (P. 24.)

54. Q. How long should treatment for shock continue?
    A. Treatment for shock should be started immediately after the bleeding has been checked and continued until the patient has been turned over to the doctor. (P. 24.)

Artificial Respiration

Electric Shock, Gas Poisoning, Suffocation, and Drowning

55. Q. How does electricity cause shock?
    A. Electricity causes shock by paralyzing the nerve centers that control breathing or by stopping the regular beat of the heart. (P. 24.)

56. Q. What are the symptoms of electric shock? (P. 24.)
    A. 1. Sudden loss of consciousness.
       2. Absence of respiration which, if present, is slight and cannot be observed.

3. Weak pulse or absence of pulse.
4. Burns at the point of contact with the conductor of electricity.

57. Q. What precautions must be taken in rescuing a person from contact with a live wire? (P. 24.)
A. 1. If a switch is near, turn off the current, but lose no time in looking for one.
2. Short circuit or ground the current on both sides of the victim by means of a drill, auger, bar, or piece of wire, taking care to release hold of the instrument before it touches the live wire.
3. Insulate yourself from the ground and remove the person from the wire. Protect yourself by using dry, nonconducting material such as clothing, dry wood, or thick paper; also, protect the hand you use to grasp the patient by your cap, coat, or any dry nonconducting material.
4. Another way is to take your belt, handkerchief, coat, a piece of dry rope, or similar material and loop it over the victim's head or foot and pull him off the wire.
5. If an ax is near at hand, use it to cut the wire on both sides of the victim, but first make certain that the handle is dry.

58. Q. What explosive gas is commonly found in coal mines?
A. Methane gas is found in many coal mines. (P. 26.)

59. Q. In what ways is methane gas dangerous?
A. If present in sufficient quantities, it will cause suffocation (lack of oxygen). It may explode and burn persons within the range of the explosion; in burning or exploding, poisonous carbon monoxide gas is often generated. (P. 26.)

60. Q. What are some of the poisonous gasses formed in mines?
A. Sulphur dioxide, oxides of nitrogen, ammonia, hydrogen sulphide, and carbon monoxide. (P. 27.)

61. Q. Is carbon dioxide gas poisonous or dangerous?
A. Carbon dioxide gas is not poisonous but may cause death by suffocation if present in sufficient quantity in the air breathed. (P. 26.)

62. Q. What treatment should be given a drowning person? (P. 31.)
A. 1. Always rescue the person from the water as quickly as possible.
2. Lock your hands under the patient's stomach and lift him several times to drain the water out of his air passages and stomach.
3. Lose no time in starting artificial respiration.

63. Q. What treatment should be given to a person suffering from suffocation or asphyxiation?
A. Remove the victim to pure air and start artificial respiration without delay. (P. 31.)

64. Q. What treatment should be given a person suffering from electric shock?
    A. Remove the person from contact with the electric conductor and start artificial respiration immediately. (P. 31.)

65. Q. What is artificial respiration?
    A. Artificial respiration is the act of causing a person to breathe artificially by alternately compressing the walls of the chest to force the air out of the lungs and allowing the walls of the chest to expand to draw fresh air into the lungs.

66. Q. When should artificial respiration be started?
    A. As quickly as possible after the accident has occurred. (P. 32.)

67. Q. How long should artificial respiration be continued?
    A. Until breathing is restored or for at least 4 hours. (P. 32.)

68. Q. What precautions must be taken before starting artificial respiration? (P.32)
    A. 1. Remove all foreign bodies from the patient's mouth.
       2. Loosen tight clothing at the neck, chest, and waist.
       3. See that the tongue is forward.

69. Q. What additional treatment would you give?
    A. The regular treatment for shock. (P. 32.)

70. Q. How many times per minute would you cause the patient to breathe in giving artificial respiration?
    A. The patient should be made to breathe 12 to 15 times per minute. (P. 35.)

71. Q. What are the commonly used methods of artificial respiration?
    A. The Sylvester method and the Schaefer or prone-pressure method. (P. 33.)

72. Q. Which method is preferable and why?
    A. The prone-pressure method is preferable because it is simpler and easier to perform. (P. 33.)

73. Q. Demonstrate the Sylvester method of artificial respiration, and show how to change operators without breaking rhythm?
    A. (Each member of class demonstrates.) (P. 36.)

74. Q. Demonstrate the prone-pressure method of artificial respiration, and show how to change operators without breaking rhythm?
    A. (Each member of class demonstrates.) (P. 33.)

<u>Hemorrhage or Bleeding</u>

75. Q. Give a definition of hemorrhage?
    A. Hemorrhage is the flow of blood from an artery, vein, or capillary. (P.46.)

76. Q. What are the symptoms of arterial bleeding?
    A. Bright red blood spurting from a wound indicates that an artery has been cut. (P. 47.)

77. Q. What are the symptoms of venous bleeding?
A. Dark red blood flowing in a steady stream indicates venous bleeding. (P. 47.)

78. Q. What are the symptoms of capillary bleeding?
A. If the blood is red and oozes from the wound it is from capillaries. (P. 47.)

79. Q. Name the methods of controlling bleeding? (P. 47.)
A. 1. Digital pressure (or placing the finger or fingers) on pressure points.
2. Tourniquet applied on pressure points.
3. Direct pressure by means of a sterile bandage applied to the wound.
4. Elevation of the injured portion.
5. Cold application.

80. Q. How would you stop the flow of blood from a wound with capillary bleeding?
A. Apply a sterile bandage compress directly over the wound. (P. 47.)

81. Q. How would you stop the flow of blood from a wound with venous bleeding?
A. Usually bleeding from a vein can be checked by applying a large sterile bandage compress directly over the wound. If this fails, the side of the wound away from the heart should be compressed. (P. 47.)

82. Q. How would you check the flow of blood from a wound with arterial bleeding?
A. When an artery is cut, temporary digital (finger) pressure should be applied on a pressure point between the wound and the heart, after which a tourniquet should be applied on the pressure point. (P. 47.)

83. Q. Why must digital pressure be applied before the tourniquet ?
A. Digital pressure is applied before the tourniquet so that no unnecessary time will be lost in checking the flow of blood. (P. 47.)

84. Q. What is meant by pressure points, and how many are there?
A. Pressure points are places on the surface of the body where pressure can be applied conveniently on the large arteries to stop the flow of blood. There are 11 pressure points on each side of the body - 22 in all. (Fig. 12, P. 48.)

85. Q. What is a tourniquet?
A. A tourniquet is a device used to apply and hold pressure on a pressure point. (Fig. 11, P. 46.)

86. Q. How long should a tourniquet remain tight over a pressure point?
A. Not more than 20 minutes, after which the tourniquet should be loosened for several seconds and then retightened if bleeding continues. (P. 45.)

87. Q. Indicate the following pressure points:
 1. Wound of scalp? (Fig. 13, P. 49.)
 2. Wound of face or nose? (Fig. 13, P. 49.)
 3. Wound of armpit or arm torn from body? (Fig. 12, P. 48.)
 4. Wound of arm? (Fig. 14, P. 49.)
 5. Wound of forearm? (Fig. 14, P. 49.)
 6. Wound of hand? (Fig. 14, P. 49.)
 7. Wound of groin? (Fig. 15, P. 50.)
 8. Wound of thigh? (Fig. 15, P. 50.)
 9. Wound of leg? (Fig. 15, P. 50.)
 A. (Each member of class demonstrates.)

88. Q. What are the symptoms of internal hemorrhage?
 A. The symptoms of internal hemorrhage are faintness, cold skin, pale face, dilated pupils, thirst, feeble and irregular breathing, sighing, clouded vision, weakness, rapid pulse, dizziness, and later loss of consciousness. (P. 52.)

89. Q. What is the treatment for internal hemorrhage?
 A. Lay the patient down with his head lower than his body, and apply ice or cold cloths to the body at the point from which the bleeding seems to come. Do not give stimulants unless absolutely necessary, but ice water or cold water may be given slowly if the patient is conscious. (P. 52.)

90. Q. Why is arterial bleeding dangerous?
 A. Arterial bleeding, if allowed to go unchecked for a short time, may cause death. Loss of blood also complicates the condition of shock.

91. Q. What is nature's method of stopping bleeding?
 A. While blood is flowing through the body it is fluid, but as soon as a blood vessel is severed the blood flowing out thickens or clots and tends to stop flowing. (P. 47.)

Wounds

92. Q. What is a wound?
 A. A wound may be defined as a break in the skin. (P. 54.)

93. Q. Name three kinds of wounds?
 A. Three kinds of wounds are the incised, lacerated, and punctured. (P. 54.)

94. Q. What is an incised wound?
 A. An incised wound is one in which the edges are divided smoothly without bruising or tearing; it is produced by some sharp cutting instrument such as a knife, piece of glass, or sharp piece of coal or rock. (P. 54.)

95. Q. What is a lacerated wound?
 A. A lacerated wound is one in which the edges are ragged as a result of tearing the skin and tissues by blunt instruments or machinery. (P. 54.)

96. Q. What is a punctured wound?
A. Punctured wounds may be produced by pointed instruments such as needles, splinters, nails, or pieces of wire. They are usually small, but they may be very deep. (P. 54.)

97. Q. What precautions must the first-aid man take in treating wounds? (P. 55.)
A. 1. If there is bleeding from an artery, check the flow of blood and apply a tourniquet.
2. Do not touch the wound with your hand, clothing, or any instrument, and do not pour water or drugs into or on it.
3. Make all dressings wide enough to cover the wound completely.
4. Apply a sterile bandage compress over the wound as quickly as possible and tie the knot over the compress.

98. Q. Under what conditions would the knot be tied in some other place than over the compress?
A. In compound fractures and in wounds of the eye, the knot should be tied at some point away from the compress. (P. 55.)

99. Q. What bandages are used in first-aid work?
A. The compress and triangular or cravat bandages. (P. 39.)

100. Q. In general, how tight should bandages be applied?
A. Bandages should be applied firmly but never tightly. (P. 56.)

101. Q. How would you dress the following injuries?
1. Wound and bleeding of scalp, temple, ear, or face. (Fig. 17, P.57.)
2. Wound and bleeding of forehead. (Fig. 18, P. 58.)
3. Wound and bleeding of nose. (Fig. 21, P. 61.)
4. Injuries of the eye. (Fig. 19, P. 60.)
5. Wound and bleeding of chin. (Fig. 22, P. 61.)
6. Wound and bleeding of neck or throat. (Fig. 23, P. 62.)
7. Wound and bleeding of shoulder. (Fig. 24, P. 69.)
8. Wound and bleeding of armpit. (Fig. 25, P. 65.)
9. Arm torn from body. (P. 66.)
10. Dressing for amputated arm. (P. 66.)
11. Wound and bleeding of upper arm. (Fig. 26, P. 68.)
12. Wound and bleeding of elbow. (Fig. 26, P. 68.)
13. Wound and bleeding of forearm. (Fig. 26, P. 68.)
14. Wound and bleeding of wrist. (P. 69.)
15. Wound and bleeding of palm of hand. (Fig. 27, P. 70.)
16. Wound and bleeding of back of hand. (Fig. 28, P. 72.)
17. Wound and bleeding between shoulders. (Fig. 30, P. 75.)
18. Wound and bleeding of back, chest, side, or abdomen. (Fig. 31,P.76)
19. Wound and bleeding of lower part of back, abdomen, or buttocks. (Fig. 32, P. 77.)
20. Wound and bleeding of groin. (Fig. 33, P. 78.)
21. Wound and bleeding of crotch. (Fig. 34, P. 79.)
22. Wound and bleeding of hip. (Fig. 35, P. 80.)
23. Wound and bleeding of thigh. (Fig. 36, P. 81.)
24. Wound and bleeding of knee. (Fig. 37, P. 82.)

25. Wound and bleeding of leg. (Fig. 38, P. 84.)
26. Wound and bleeding of ankle or foot. (Fig. 39, P. 85.)
27. Wound and bleeding of foot. (Fig. 40, P. 86.)

A. (Each member of class demonstrate.)

Dislocations

102. Q. What is a dislocation?
A. A dislocation is the slipping of a bone out of its socket. (P. 91.)

103. Q. What other injury always accompanies a dislocation?
A. The ligaments about a dislocated joint are always torn. (P. 91.)

104. Q. What are the symptoms of dislocation?
A. The symptoms of dislocation are (1) deformity is present; (2) the head of the bone can usually be felt; (3) the limb in which the joint is dislocated may be either longer or shorter than the uninjured limb; (4) it is impossible to place the dislocated limb in its natural position; and (5) pain and swelling accompany it. (P. 91.)

105. Q. In general, how would you treat dislocation?
A. Apply dressings or splints in line of deformity, and treat for shock if necessary. (P. 92.)

106. Q. Is it proper for the first-aid man to reduce certain dislocations?
A. Yes. (P. 92.)

107. Q. What dislocations may the first-aid man reduce?
A. The first-aid man may reduce dislocations of the fingers, toes, and lower jaws. (P. 92.)

108. Q. How would you dress or treat the following injuries?
1. Dislocation of finger or thumb. (P. 96.)
2. Dislocation of lower jaw. (P. 92.)
3. Dislocation of shoulder. (Fig. 42, P. 95.)
4. Dislocation of elbow. (Figs. 43 and 43 A, pp. 94, 97, 98.)
5. Dislocation of hip. (Fig. 44, P. 100.)
6. Dislocation of knee. (Fig. 45, P. 101.)

A. (Each member of class demonstrates.)

Fractures

109. Q. What is a fracture?
A. A fracture is a broken bone. (P. 101.)

110. Q. Name the two kinds of fractures treated in first-aid work?
A. Simple and compound fractures. (P. 101.)

111. Q. Define a simple fracture?
A. A simple fracture is one in which the bone is broken but there is no open wound in connection with the fracture. (P. 101.)

112. Q. Define a compound fracture?
A. A compound fracture is one in which there is an open wound communicating with the bone at the place of fracture. (P. 101.)

113. Q. What may happen when a simple fracture is improperly handled?
A. A simple fracture, by careless or improper handling, may be converted into a compound fracture. (P. 101.)

114. Q. How may a simple fracture be converted into a compound fracture?
A. A broken bone usually has sharp, saw-toothed edges, and a little twist may force it through the skin. (P. 101.)

115. Q. What are the symptoms of a fracture?
A. The symptoms of a fracture are (1) pain and tenderness at the point of fracture; (2) inability of patient to move the broken limb; (3) a grating sensation when the limb is handled; and (4) shortening or bending of the limb compared with a similar part of the uninjured side. (P. 102.)

116. Q. In general, what precautions should be taken in treating fractures? (P. 102.)
A. 1. Have the injured person lie down, and do not move him unless absolutely necessary until splints have been applied.
2. Place the limb in as nearly natural a position as possible by taking hold of the lower part of the limb and pulling it gently and steadily.
3. The under part of the limb should be supported on both sides of the break in order to steady the bone until splints have been applied.

117. Q. What special precautions must be taken when treating compound fractures? (P. 103.)
A. 1. If arterial bleeding is present, check with temporary pressure and apply a tourniquet tightly.
2. Apply a tourniquet loosely on the pressure point above the fracture if bleeding is not present.
3. Dress the wound with a sterile bandage compress and a cravat or triangular bandage.
4. If bones are protruding do not tie knots over compress.
5. Do not attempt to pull the limb into normal position if bones are protruding.

118. Q. What are the symptoms of a fracture of the skull?
A. Blood and serum may flow from the ears, and bleeding may be seen in the eyes, nose, and mouth; the victim may be conscious or unconscious. (P. 104.)

119. Q. What treatment is given for a fracture of the skull?
A. Place the head on a folded blanket or coat so that there is no pressure on the fracture. If a compound fracture exists, check the bleeding by placing a large bandage compress over the wound and tie

it firmly in place with the knot away from the wound. Cover the compress with a cravat bandage and treat for shock, but do not give stimulant. (P. 104.)

120. Q. How would you treat a fracture of the nose?
A. Apply a bandage compress, not too tightly, as for wound of the nose. (P. 104.)

121. Q. How would you dress and treat the following fractures?
1. Dressing for fracture of jaw. (P. 105.)
2. Dressing for fracture of collar bone. (P. 105.)
3. Dressing for fracture of arm. (Fig. 46, P. 107.)
4. Dressing for fracture of elbow. (Fig. 43, P. 98.)
5. Dressing for fracture of forearm. (Fig. 47, P. 110.)
6. Dressing for fracture of wrist. (Fig. 47, pp. 109, 110.)
7. Dressing for fracture of hand. (Fig. 48, P. 112.)
8. Dressing for fracture of shoulder blade. (P. 105.)
A. (Each member of class demonstrates.)

122. Q. What are the symptoms of fracture of the rib?
A. The symptoms of fracture of the rib are severe pain in breathing, tenderness over the suspected fracture, and inability to take a long breath because of the pain produced. (P. 111.)

123. Q. How would you treat and dress fracture of the rib? (Fig. 49, P. 114.)
A. (Each member of class demonstrates.)

124. Q. What are the symptoms of fracture of the spine or broken back?
A. The patient may be paralyzed from the waist down and will be unable to move his legs. Deformity may be present at the point where the spine has been fractured. (P. 113.)

125. Q. If the patient's back is bent at the point of fracture, what would be the procedure?
A. Do not try to straighten patient if his back is bent. Treat for shock, and send for the doctor. (P. 113.)

126. Q. What is the procedure for dressing a fracture of the spine if the patient is in a straight position? (Fig. 50, pp. 113,117.)
A. (Each member of class demonstrates.)

127. Q. What are the symptoms of fracture of the pelvis?
A. The patient complains of severe pain through the pelvis. (P. 116.)

128. Q. How would you dress and treat the following fractures?
1. Fracture of pelvis. (Fig. 51, P. 118.)
2. Compound fracture of thigh with arterial bleeding. (Fig. 52, P. 120.
3. Fracture of kneecap. (Fig. 53, P. 121.)
4. Fracture of leg or ankle. (Fig. 54, P. 122.)
5. Fracture or crushing of foot or toes. (Fig. 55, P. 124.)
A.(Each member of class demonstrates.)

Burns or Scalds

129. Q. Define a burn?
A. A burn is an injury caused by application of heat, either dry or moist. Chemicals, such as strong acids or alkalies, will also cause burns. (P. 124.)

130. Q. How should clothing be removed from a burn?
A. Remove all loose clothing, but do not try to remove clothing that adheres to the skin - cut around it. (P. 125.)

131. Q. Where and how should the dressings be applied after a burn or scald?
A. Exclude the air as quickly as possible by applying picric acid gauze moistened with steam or water to all burned surfaces. (P. 125.)

132. Q. Define picric acid gauze?
A. Picric acid gauze is a sterile gauze treated with 0.5 to 1 percent picric acid solution. (P. 125.)

133. Q. What precautions must be taken in treating burns? P. 125.)
A. 1. Don't bind burned surfaces together.
2. Don't apply bandages too tightly.
3. Don't fail to be aseptic.

134. Q. How would you treat and dress the following burns?
1. Burns of head, face, and neck. (Fig. 56, P. 127.)
2. Burns of the entire body above the waistline, including upper extremities, but not of the head, face, or neck. (Figs. 57-60,62, pp. 129-132, 136.)
3. Burns of entire body below the waistline, including lower extremities. (Fig. 62, P. 136.)
A. (Each member of class demonstrates.)

General

135. Q. What are bruises, and how are they caused?
A. Bruises are injuries to the tissues under the skin in which many of the small blood vessels may be broken. They are caused by falling or striking some part of the body or being struck by some object.(P.90.)

136. Q. What are the symptoms of bruises?
A. The symptoms of bruises are immediate pain from the injury to the nerves, swelling, black and blue marks, and, later, pain from pressure of the blood on the nerves, which is increased by movement. (P. 90.)

137. Q. What treatment would you give a bruise?
A. Apply an ice bag or cold wet towel and rest the injured part. (P. 90.)

138. Q. What is a strain, and how is it caused?
A. A strain is overstretching of the muscles. It may be caused by a sudden wrench, as in lifting heavy weights. In severe strains, small blood vessels may be broken. (P. 91.)

[illegible]

139. Q. How would you treat a strain?
A. Have the injured person rest, and rub the affected parts gently with alcohol and water or witch hazel. (P. 91.)

140. Q. What is a sprain, and how may it be caused?
A. A sprain is injury to a joint. It may be caused by violent stretching, twisting, or partial breaking of the ligaments about a joint. (P.91.)

141. Q. How would you treat a sprain?
A. Elevate the joint and place it at absolute rest, apply hot towels over the injury several times, place a cravat bandage firmly around the joint, and send the injured person to the doctor. (P. 91.)

142. Q. What are the symptoms of rupture?
A. A sharp stinging pain, sickness at the stomach, and a feeling that something has given way. A lump will appear in the groin. (P. 135.)

143. Q. What is the first-aid treatment for rupture?
A. Place the patient on his back with his knees well raised toward the abdomen and his legs supported with a pillow or folded jacket. Then place cloths wet in cold water over the hernia or lump, and send for the doctor immediately. Never force the patient to lie in a straight position. (P. 135.)

144. Q. How are poisons classified?
A. There are corrosive poisons and irritant poisons. (P. 137.)

145. Q. Name some of the corrosive poisons? (P. 137.)
A. 1. Hydrochloric acid.
2. Sulphuric acid.
3. Nitric acid.
4. Potash, caustic potash, or lye.
5. Soda or caustic soda.
6. Quicklime.
7. Strong ammonia water.

146. Q. How do corrosive poisons act on the system?
A. Corrosive poisons corrode or eat away the tissues with which they come in contact. (P. 137.)

147. Q. How may corrosive poisoning be recognized?
A. Corrosive poisoning may be recognized by the characteristic stain left on the lips or mouth, also by intense burning pain in the throat, gullet, and stomach. (P. 137.)

148. Q. What treatment should be given if the poisoning was caused by an acid?
A. Counteract the poison by giving the patient baking soda in solution, lime mixed with water, or dilute ammonia water. Soothe the corroded parts with oils, treat for shock, and give stimulants. (P. 138.)

149. Q. What treatment should be given if the poisoning was caused by an alkaline?
A. Counteract the poison by giving the patient diluted acids such as vinegar or lemon juice. Soothe the corroded parts with oils, treat for shock, and give stimulant. (P. 138.)

150. Q. Name some of the irritant poisons? (P. 138.)
A. 1. Bichloride of mercury or antiseptic tablets.
2. All the combinations of lead, zinc, and copper.
3. Rat poison, which usually is a compound of arsenic.
4. Matches or phosphorus.
5. Antimony.
6. Fly poison.

151. Q. How do irritant poisons act on the system?
A. Irritant poisons when swallowed irritate the throat and stomach and are absorbed in the stomach, thus poisoning the system. (P. 138.)

152. Q. How may irritant poisoning be distinguished from corrosive poisoning?
A. The symptoms are much the same for irritant poisoning as for corrosive poisoning except that the lips and mouth are not stained. (P. 138.)

153. Q. What treatment should be given for irritant poisoning?
A. For irritant poisoning make the patient vomit by means of an emetic or run finger down patient's throat. Give large quantities of water or salt water, mustard water, or alum water. Give white of eggs, oils, or Epsom salts. Treat for shock. Give stimulant freely. (P. 139.)

154. Q. What are the symptoms of alcoholic poisoning?
A. The symptoms of alcoholic poisoning are unconsciousness, partial or complete; face flushed or bloated, but sometimes pale; skin cool and moist; eyeballs red, but not insensitive to touch. There is no paralysis. (P. 139.)

155. Q. What is the treatment for alcoholic poisoning?
A. For alcoholic poisoning give an emetic, after which give strong coffee or aromatic spirits of ammonia. Apply heat around patient; rub extremities toward body to increase circulation. (P. 139.)

156. Q. How can you distinguish alcoholic poisoning from apoplexy?
A. In apoplexy the pupils of the eye are of unequal size, the eyeballs are insensitive, and paralysis is present. (P. 139.)

157. Q. Describe the treatment for apoplexy?
A. Have patient rest in dark room, keep head and shoulders high on pillows, apply cold cloths to head, give no stimulants, and give nothing that will cause vomiting. (If in doubt, treat for apoplexy.) (P. 140.)

158. Q. How may carbolic acid poisoning be recognized?
A. The bottle that contained the poison may be found. Patient will vomit and suffer great pain; there will be a strong odor of carbolic acid; lips, tongue, and mouth of patient will be burned white by pure acid and black by impure acid. (P. 140.)

159. Q. What is the treatment for carbolic acid poisoning?
A. Give vinegar, soapsuds, or raw whites of eggs in water. Produce vomiting; give a solution of Epsom or Glauber salts or sodium phosphate well diluted to hasten elimination of acid that may have entered the circulation; keep patient warm. For collapse, give strong coffee. Apply artificial respiration if breathing stops. (P. 140.)

160. Q. What precautions should be taken before loading a man on a stretcher?
A. Test the stretcher to make certain that it will bear the patient's weight. (P. 169.)

161. Q. On which side is it preferable to have the three men lift when loading on or unloading from stretcher?
A. On uninjured, unless location of injuries makes it desirable to lift from the injured side.

162. Q. In marching with stretcher, do all men keep in step? Why?
A. No, rear man breaks step to stop swinging of stretcher and jarring patient. (P. 177.)

163. Q. What is heat exhaustion?
A. Heat exhaustion is collapse from the effects of heat. (P. 185.)

164. Q. What are the symptoms of heat exhaustion?
A. The symptoms of heat exhaustion are the same as those indicating shock. (P. 185.)

165. Q. What is the treatment for heat exhaustion?
A. The treatment for heat exhaustion is the same as that for shock. (P. 185.

166. Q. What is the cause of sunstroke?
A. Sunstroke is caused by prolonged exposure to the rays of the sun or by excessive heat indoors. (P. 184.)

167. Q. What are the symptoms of sunstroke? (P. 184.)
A. 1. The patient is unconscious.
2. The face is red and flushed.
3. The skin is hot and dry.
4. No perspiration whatsoever is present.
5. The breathing is labored and of a snoring character.
6. The pupils are enlarged.
7. The pulse is slow and full.

168. Q. What first-aid treatment would you give for sunstroke? (P. 184.)
A. 1. Reduce the temperature of the body as quickly as possible.
2. Remove patient to a cool place.
3. Raise patient's head by placing on a folded coat or blanket.
4. Remove clothing.
5. Apply ice or cold water to head and body.
6. Rub extremities toward the heart to prevent shock.
7. Do not give stimulant.

169. Q. How would you treat frostbites or freezing?
A. Rub the affected part with snow or cold water, after which use warmer water gradually. Give the patient a liquid stimulant. Do not expose the affected parts to heat immediately after they have been frostbitten or frozen. (P. 185.)

170. Q. What first-aid treatment would you use for snake bite? (P. 185.)
A. 1. Apply tourniquet just above the wound between the wound and the heart, tight enough to stop the circulation of the blood.
2. Open the holes made by the snake's fangs, cutting lengthwise of the limb.
3. Let the blood run from the cut, and at the same time rub the wound with the fingers to dislodge any of the poison that remains.
4. Loosen tourniquet every 20 minutes for 5 seconds.

171. Q. How should a patient be prepared for transportation, loaded on improvised or army-type stretcher, and transported? (P. 141, Figs. 91-94; pp. 176, 178-180.)
A. (Each member of class demonstrates.)

I. C. 6854

October 1935

Department of the Interior

UNITED STATES BUREAU OF MINES
John W. Finch, Director

INFORMATION CIRCULAR

INDUCTION PROSPECTING FOR SHALLOW ORE DEPOSITS AND SMALL METALLIC OBJECTS

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J. W. Joyce

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

INDUCTION PROSPECTING FOR SHALLOW ORE DEPOSITS AND SMALL METALLIC OBJECTS[1]

By J. W. Joyce[2]

CONTENTS

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U.S. Bureau of Mines Information Circular 6854."

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INTRODUCTION

The geophysical section of the United States Bureau of Mines has received many inquiries regarding the application of geophysical methods to the location of small, buried metallic objects.

The object of this paper is fourfold: (1) To sketch as briefly and non-technically as possible the principles underlying the operation of several electrical geophysical methods of prospecting applicable to the finding of small, buried metallic objects; (2) to point out the possibilities and limitations of these methods; (3) to present, whenever possible, data showing actual results obtained from their use; and (4) to enumerate and describe methods that lack scientific background or foundation.

Elementary Principles

In discussing the principles underlying the operation of some of the electrical methods of geophysical prospecting certain technical terms, such as "magnetic field", "induced voltage", "reactance", and "resonance", inevitably must be used. For the benefit of the reader unfamiliar with their meaning a brief exposition of these terms is presented.

Magnetic field. - Everyone is familiar with the ordinary bar magnet and its ability to attract pieces of iron or steel. If such a magnet is placed under a sheet of paper covered with a thin layer of fine iron filings and the paper is jarred slightly the filings will aline themselves in a pattern similar to that shown in figure 1. This simple experiment demonstrates the existence of a magnetic field of force about the magnet. This field is composed of numerous lines of force, indicated by the lines of iron filings.

The region over which the lines of force enter the magnet is called the south pole and the opposite end, where the lines of force leave the magnet, the north pole. Every magnet always has a north and a south pole.

At every point about the magnet the magnetic field has a definite direction- the direction of the lines of force - and a definite strength or intensity; the nearer the point to one of the poles the greater the intensity. (See fig. 1.) This can be shown experimentally by moving a piece of iron toward one end of a horseshoe or bar magnet; the nearer the piece to the end the stronger the force of attraction acting on it.

The intensity and direction at any point in a magnetic field may be represented by a straight line that points in the direction of the field and is proportional in length to the strength of the field, as shown at points A, B, and C, figure 1.

In addition to permanent magnets there are electro-magnets. One of the fundamental discoveries of electricity was the fact that whenever a current flowed in an electric conductor a magnetic field surrounded the conductor, as shown in figure 2,A. Furthermore, the strength of the magnetic field in air was found to be directly proportional to the current in the wire. Thus, if the current was doubled the strength of the magnetic field also doubled.

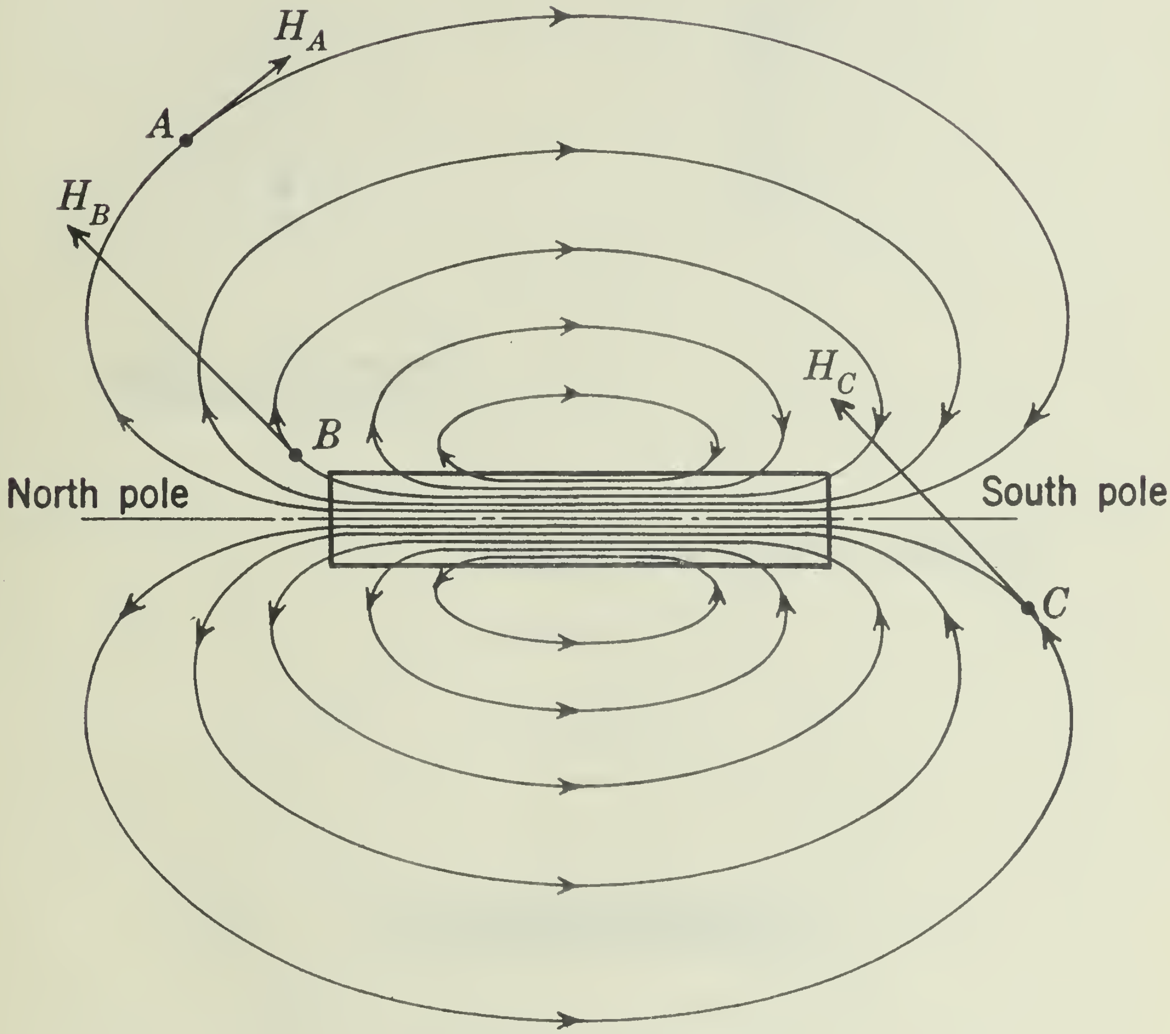

Figure 1.— Magnetic field of bar magnet.

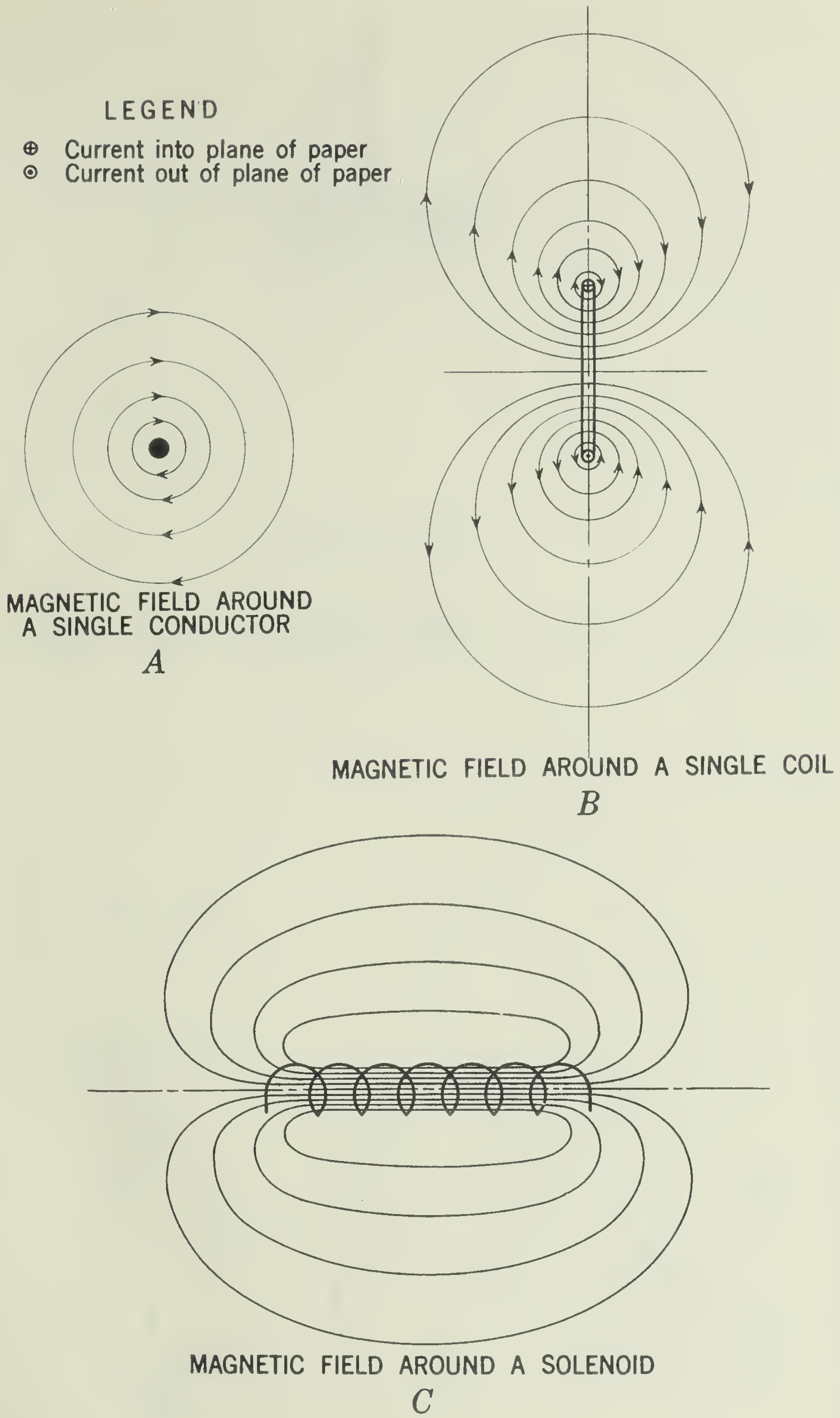

Figure 2.—Electromagnetic fields: *A*, Magnetic field around a single conductor; *B*, magnetic field around a single coil; *C*, magnetic field around a solenoid.

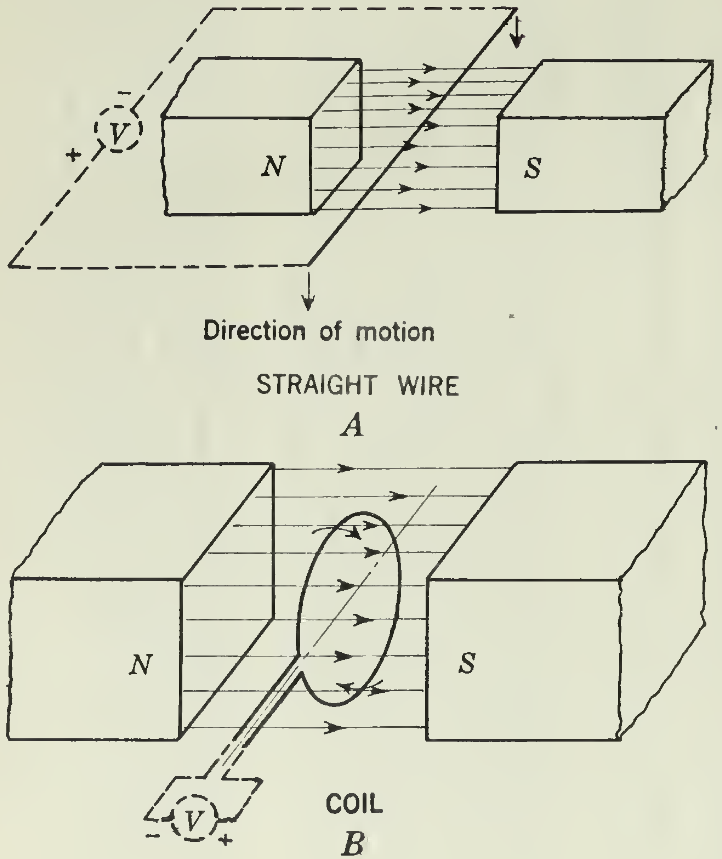

Figure 3.— Electromagnetic induction: A, Straight wire; B, coil.

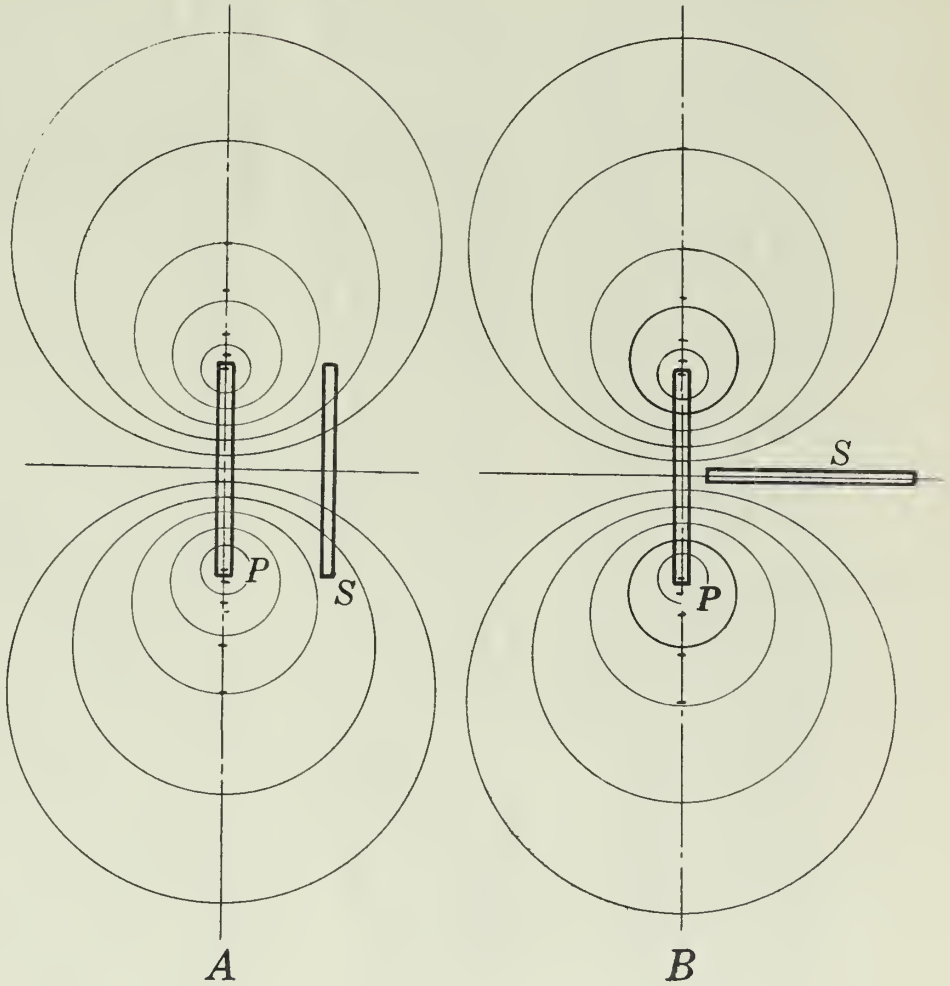

Figure 4.— Mutual inductance.

If a single turn of wire is wrapped around a wooden form and a current is passed through the wire a magnetic field will surround the loop (fig. 2,B). If this same current is now passed through 5 turns of wire instead of 1 turn the resulting magnetic field will be 5 times as strong, because each turn is producing a magnetic field which adds to the field of every other turn. Thus, if a current of I amperes is passed through a coil of N turns of wire (fig. 2,C), the resulting magnetic-field strength will depend on the product NI. This product is referred to as the "ampere-turns" of the coil.

When a coil is connected to a source of constant voltage a direct current flows, and the resulting magnetic field is steady. If an alternating voltage is used the current, and hence the magnetic field, will also alternate from positive to negative values; that is, at one time the magnetic field will be in one direction, and an instant later it will have changed to the opposite direction. Thus, there are alternating as well as direct magnetic fields. In the methods to be described only alternating fields are used.

Induced voltage. - If an electrical conductor, such as a piece of wire or a metal bar, is moved through a steady magnetic field so that it cuts across the lines of force, as shown in figure 3,A, a voltage or potential difference will exist between the two ends of the conductor. The amount of this voltage will depend on the total rate at which the conductor cuts the lines of force. For example, suppose a conductor cuts lines of force at the rate of 100,000,000 a second; then the potential difference between the ends of the conductor will be 1 volt. If the rate of cutting is increased a hundred times the potential difference will now be 100 volts. The rate of cutting may be increased by increasing the length of the wire in the field, increasing the strength of the field, increasing the speed of cutting, or combinations of these methods.

As soon as the conductor ceases to cut magnetic lines of force the voltage across the ends becomes zero.

Suppose, instead of a straight conductor, a circular coil of wire of one turn, as shown in figure 3,B, is used. If this coil is rotated so that the number of lines of magnetic force through it changes a voltage will appear across the two ends of the coil. This voltage will depend on the rate at which the lines of force inside the loop increase or decrease. Thus, if the rate of change is 100,000,000 lines a second, 1 volt will be generated in the coil. Now, if instead of having only 1 turn of wire the coil had 10 turns then for the same rate of change of lines of magnetic force, 10 volts would be generated, since each turn adds to the voltage of every other turn.

Up to this point it has been assumed that the conductor moved and the magnetic field remained stationary. The same result would have been obtained if the conductor remained stationary and was cut by a moving magnetic field. The law of induction states that whenever a conductor cuts lines of magnetic force as a result of any relative motion between the conductor and the magnetic field a voltage will be generated in the conductor.

Again, if a conductor is placed in an alternating magnetic field - that is, a magnetic field that is continually passing from the maximum value in one direction to the corresponding maximum in the opposite direction - an alternating voltage of the same period or frequency as the magnetic field will be generated in the conductor.

Self-inductance. - If a coil of wire is connected to a direct or steady voltage, as, for example, a battery, the resulting current will be determined by the resistance of the coil. If this same coil is now connected to an alternating voltage equal to the preceding direct voltage the alternating current in the coil will be less than the direct current. In other words, something besides resistance now impedes the flow of current. This quantity is the opposing voltage of self-inductance of the coil. It is due to the fact that the alternating current flowing in the coil produces an alternating magnetic field. This field cuts the turns of wire on the coil and generates an alternating voltage which always opposes the applied voltage.

E = applied alternating voltage,
I = resulting current through coil,
E_L = countervoltage of self-inductance coil,
X_L = inductive reactance of coil,
f = frequency of applied alternating voltage,
π = 3.1416.

Then $E_L = IX_L$ and $X_L = 2\pi fL$.

Factor L is known as the coefficient of self-inductance of the coil. For any one coil it is a constant, and its value depends on the shape, size, method of winding, and number of turns of the coil.

Mutual inductance. - Consider two coils placed as shown in figure 4,A. If an alternating current flows in coil P the resulting alternating magnetic field will cut coil S, and voltage will be generated in the latter. At any particular separation of the coils the maximum lines of force from P will cut S when P and S are parallel (fig. 4,A). If S is now turned until it is in the position shown in figure 4,B, none of the lines of force from P pass through S, and hence no voltage is generated in the latter.

Let X_M = voltage generated in S due to unit current in P,
f = frequency of current in P,
π = 3.1416,
$X_M = 2\pi fM$.

Here, M is known as the coefficient of mutual inductance between P and S. It depends on the shape, size, methods of winding, and turns on P and S and their positions relative to each other. For the case shown in figure 4,B, M is equal to zero.

Capacity. - An electric condenser consists of two metal plates separated by some insulating material, such as air, mica, paper, oil, or similar substances. When placed in series with a source of direct voltage, barring a small initial

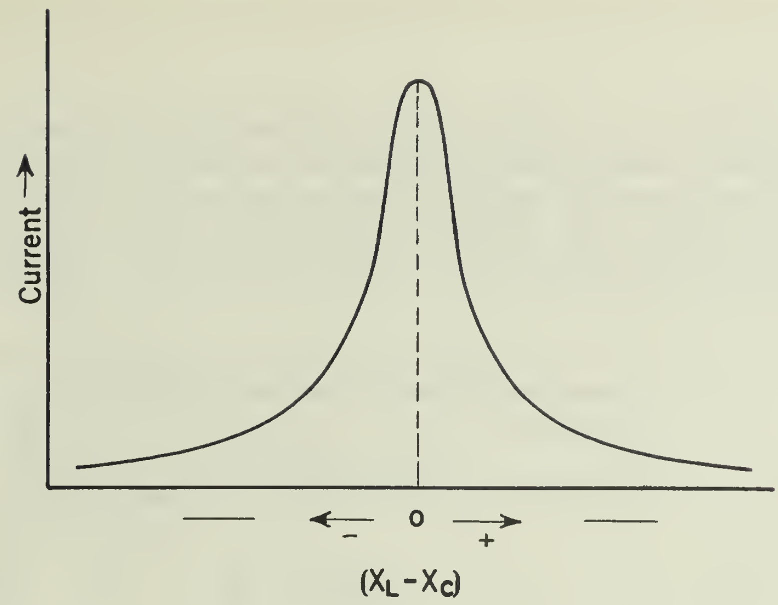

Figure 5.—Relation between current and reactance.

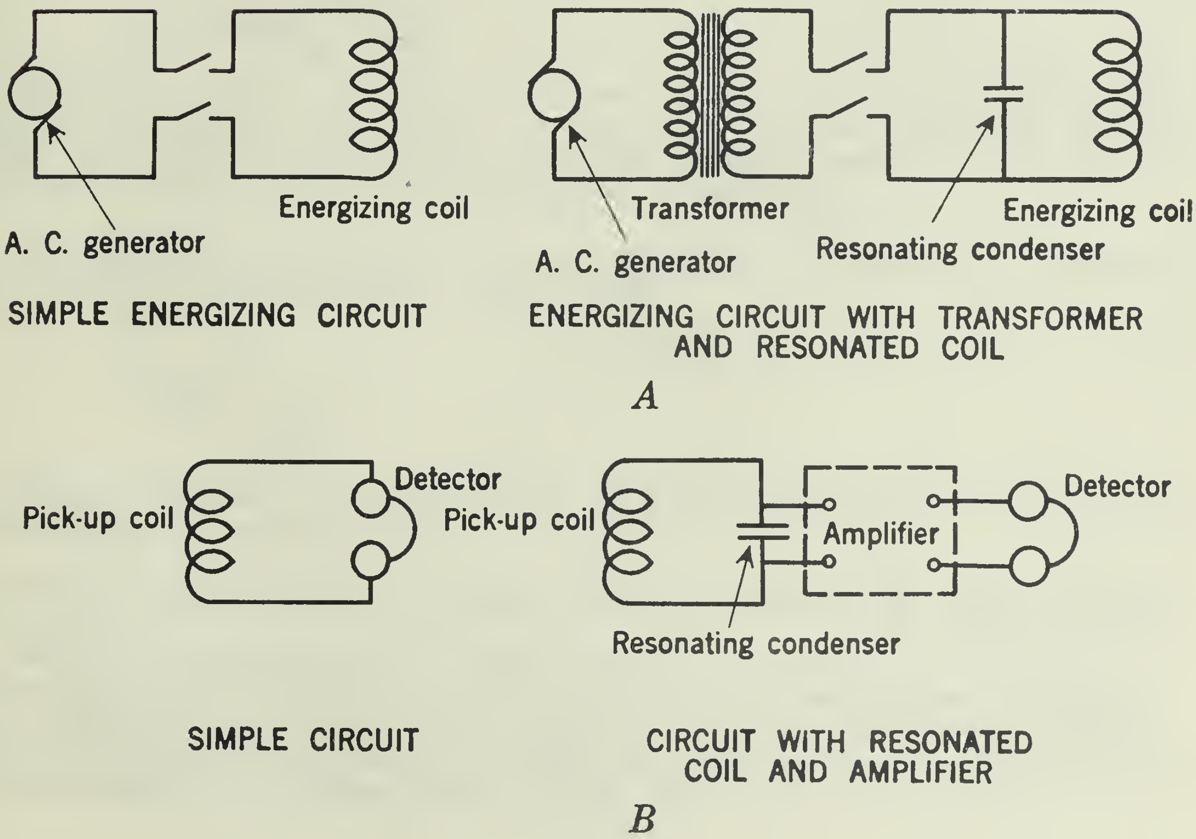

Figure 6.—*A*, Energizing circuits; *B*, pick-up circuits.

transient, no appreciable current will flow; that is, the condenser completely blocks off any current. However, if an alternating current is used current will flow, the amount depending on the capacity of the condenser and the frequency of the applied voltage. The capacity is constant for a given condenser; it depends on the shape, size, and separation of the plates and the insulating material between them.

Let $\underline{E}$ = applied alternating voltage,
$\underline{I}$ = resulting current through condenser,
$\underline{X_c}$ = capacity reactance due to condenser,
$\underline{C}$ = capacity of condenser,
$\underline{f}$ = frequency of $\underline{E}$, the applied voltage,
π = 3.1416.

Then $\underline{I} = \dfrac{\underline{E}}{\underline{X_c}}$ and $\underline{X_c} = \dfrac{1}{2\pi \underline{fC}}$

Impedance. - When an alternating current flows through an electrical circuit containing resistance ($\underline{R}$), inductive reactance ($\underline{X_L}$), and capacitive reactance ($\underline{X_c}$) the current is impeded by all three quantities. This combined effect is called the total impedance ($\underline{Z}$) of the circuit, and its value is found to be

$$\underline{Z} = \sqrt{\underline{R}^2 + (\underline{X_L} - \underline{X_c})^2} \ .$$

Resonance. - In an alternating-current circuit the inductive and capacitive reactances act against each other. If they are made equal their combined effect becomes zero, and the total impedance of the circuit becomes equal to its resistance. This is known as the condition of resonance.

The relationship between inductance, capacity, and frequency at resonance can be found by making $\underline{X_L}$ equal to $\underline{X_c}$. Thus,

$$\underline{X_L} = \underline{X_c}$$

$$2\pi \underline{fL} = \frac{1}{2\pi \underline{fC}} \ .$$

If any 2 of the 3 quantities $\underline{L}$, $\underline{C}$, and $\underline{f}$ are given the other may be found by solving the above equation.

Figure 5 shows the way in which the current varies as $\underline{X_L} - \underline{X_c}$ is varied.

Since at resonance the only factor limiting the current is resistance it follows that the current will be the maximum for a given voltage. A familiar example which utilizes resonance to produce maximum current flow for a given voltage is found in the tuning of a radio set. Here the value of the capacity is changed until the maximum volume is obtained.

INDUCTION METHODS

General

Induction methods of geophysical prospecting usually embrace four cardinal features: (1) A source of electrical energy, (2) a primary or exciting loop, (3) one or more exploring or pick-up coils, and (4) a detecting device. Each of these factors, together with other points of interest, will be discussed in a general way before specific methods are described.

Source of electrical energy. - The source of electrical energy used depends on the frequency of alternating current desired. At frequencies below 1,000 cycles per second hand-driven or small gasoline-driven alternators sometimes are used, while above that value vacuum-tube oscillators meet the need. The latter usually receive their energy from generators or batteries. They simply change the direct or low-frequency alternating current of the generator or batteries to higher-frequency currents. Unless otherwise noted, most of the induction methods described in this report may be effectively operated at a frequency of 500 cycles per second.

Primary or exciting loop. - The electrical energy produced by the generator or oscillator is supplied to the primary or energizing loop, which translates the electrical energy into magnetic energy in the form of an alternating magnetic field of frequency equal to the frequency of the supplied electrical current.

The size and location of the primary loop depend on the particular method used, but in all cases it is so placed that the portion of the ground to be explored is subjected to the primary magnetic field.

Exploring or pick-up coils. - Exploring or pick-up coils are used to determine and map out the shape of the magnetic field over the ground being investigated. This is done by observing the induced voltages in the pick-up coil or coils when placed in various directions at different points on the ground.

Detecting device. - The purpose of the detecting device is to convert the voltage of the exploring coil into an audible sound or the visible deflection of a meter. At frequencies below 100 the alternating voltage of the exploring coil is rectified and indicated on a sensitive meter. From 100 to about 3,000 cycles per second ordinary radio headphones act as detectors, changing the voltage to an audible note. Above this range vacuum-tube voltmeters may be used in conjunction with an amplifier and a suitable meter.

Maximum effective range. - To realize the greatest possible effective range for any induction method two conditions must be met. First, the maximum number of ampere-turns in the primary loop for a given source of energy as well as the largest practical coil area must be obtained; second, effective amplification of the pick-up-coil voltage must be realized.

To obtain the maximum number of ampere-turns in an energizing coil the impedance of the latter must be decreased enough to allow the maximum current available from the generator to flow in the coil. As has been pointed out, the impedance is made up of inductive reactance and resistance. Inductive reactance may be eliminated by resonating the coil with a condenser of proper size connected across its terminals. Resistance may be diminished by increasing the size of the wire, although practical considerations limit the use of excessive sizes. The same is true of the number of turns and the size of the coil.

If, when the coil is resonated, its impedance allows a current greater than the maximum allowable generator current to flow a step-down transformer may be used to reduce the voltage to the coil terminals.

As a numerical example of the foregoing statements consider a generator having a maximum energy output of 250 volt-amperes at 100 volts, giving a full-load current of 2.5 amperes. Assume a frequency of 500 cycles per second. Let 100 ohms represent the impedance of the energizing coil 10 ohms of resistance and 99.5 ohms of an inductive reactance. If a condenser having a capacity of 0.0000032 farad is connected across the coil the inductive reactance vanishes, and the total impedance is reduced to 10 ohms; but if the 100-volt generator supply is connected directly across the energizing loop 10 amperes will flow, whereas the full-load generator current is only 2.5 amperes. However, if a step-down transformer having a ratio of 2 to 1 is used the secondary voltage will be 50 volts, giving a coil current of 5 amperes or 250 watts input to the coil; if the transformer losses are neglected this just equals the generator full-load output. Thus, without resonance the exciting-loop current would be only 1 ampere, whereas by using a resonating condenser and the proper step-down transformer 5 amperes would flow, a clear gain of 5 in the effective ampere-turns of the primary magnetic field.

Even more essential to increased sensitivity than a large number of primary ampere-turns is the amplification of the pick-up-coil signals. First, the pick-up coil should be resonated with a condenser connected in series with it. The voltage across this condenser is then fed into a suitable amplifying unit, the output of which goes to the detector.

Typical diagrams of connections for the energizing coil and pick-up-coil systems are shown in figure 6.

Detailed descriptions and discussions of specific induction methods of prospecting appear in a later section of this report.

Objects Detectable by Induction Methods

Only metallic objects of appreciable size can be detected by induction methods. Iron chests and pots, large tin cans, and similar containers react favorably, whereas wooden or earthenware objects can produce no effects whatever, since they are neither conducting nor magnetic. It is doubtful if small quantities of coins alone could produce a measurable reaction, as they are nonmagnetic and, although conducting, do not offer large enough volumes or continuous paths for the secondary currents to produce appreciable effects. Certainly, individual scattered coins cannot be found by these methods.

Optimum Frequency

Experience has indicated that frequencies in a range of 200 to 1,000 cycles per second are most satisfactory for induction methods of prospecting. An average value of 500 cycles per second is very convenient. Generators are obtained easily, and ordinary radio headphones can be used as a detector. Under these conditions zero voltage in the pick-up coil is evidenced by silence in the headphones, whereas secondary voltage causes an audible buzzing.

Stationary Primary Loop and Single Pick-up Coil

This method is best adapted to small areas which can be entirely surrounded by a large horizontal primary loop laid on the ground or supported a short distance above it on stakes. Actually, the loop should enclose the ground to be tested plus a strip 20 to 30 feet wide surrounding it in order to have a uniform magnetic field over the test area. (See fig. 7.) Close to the wires the magnetic lines are curved, making interpretation of anomalies in this part of the field difficult. By keeping the pick-up coil as close to the plane of energizing loop as possible still greater field uniformity is realized.

For shallow work this method should be limited to areas of less than 100 feet on a side, corresponding to an exciting loop 140 feet on a side. If a larger coil is used, even with many turns of wire, the magnetic field is too extensive and weakened too much to be effective.

The single exploring coil is mounted on a tripod in such a way that it may be rotated about both a vertical and a horizontal axis. This arrangement allows the operator to adjust the plane of the coil in any direction until it is made parallel to the magnetic field at the point of observation, as evidenced by zero voltage in the exploring coil.

The exploring coils used by the Bureau of Mines in making induction surveys of large ore bodies ranged in size from a 30-inch-diameter coil having 840 turns of No. 26 double cotton-covered wire to a 2- by 3-foot rectangular coil having 400 turns of No. 26 d. c. c. wire. The latter was more effective for nonresonant conditions, although in a search for relatively small metallic objects the circular coil with resonance should be more suitable. Figure 7,B, shows electrical connections for the pick-up-coil circuit, and figure 8 is a sketch of the mounting arrangement of the rectangular coil. Figure 9 illustrates the operating principles of this method.

Consider a section of ground devoid of any conducting bodies, as shown in figure 9,A. For such an area the primary magnetic field due to the energizing loop is represented by the series of solid lines. If a small search coil is placed in position a in such a field magnetic lines of force will pass through it, as shown, and in accordance with the laws of induction a voltage will be generated in the search coil. If the coil is now placed in position b parallel to the magnetic field the lines of force no longer pass through the coil, and no voltage is generated in it. Thus, the direction of the magnetic field at

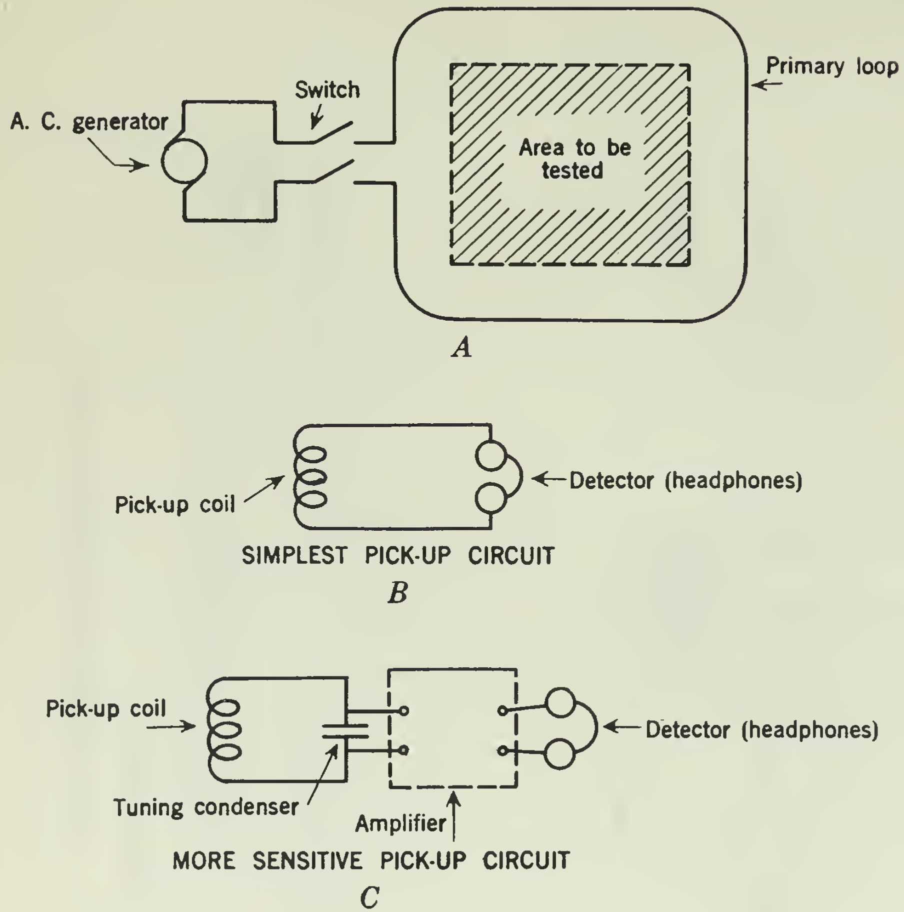

Figure 7.—*A*, Primary loop and single pick-up circuits; *B*, simplest pick-up circuit; *C*, more sensitive pick-up circuit.

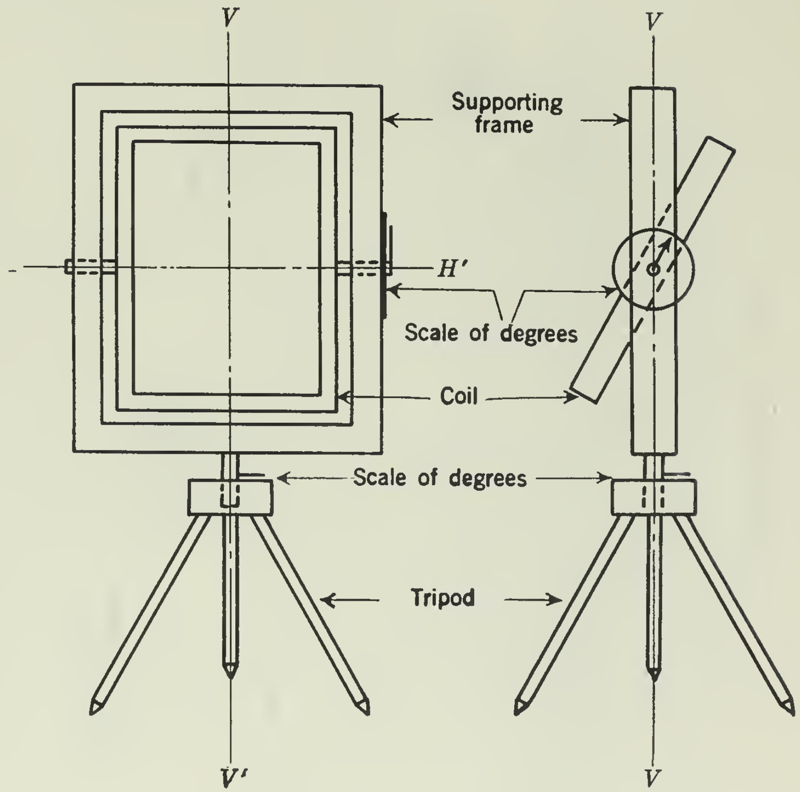

Figure 8.—Mounting arrangement of rectangular pick-up coil.

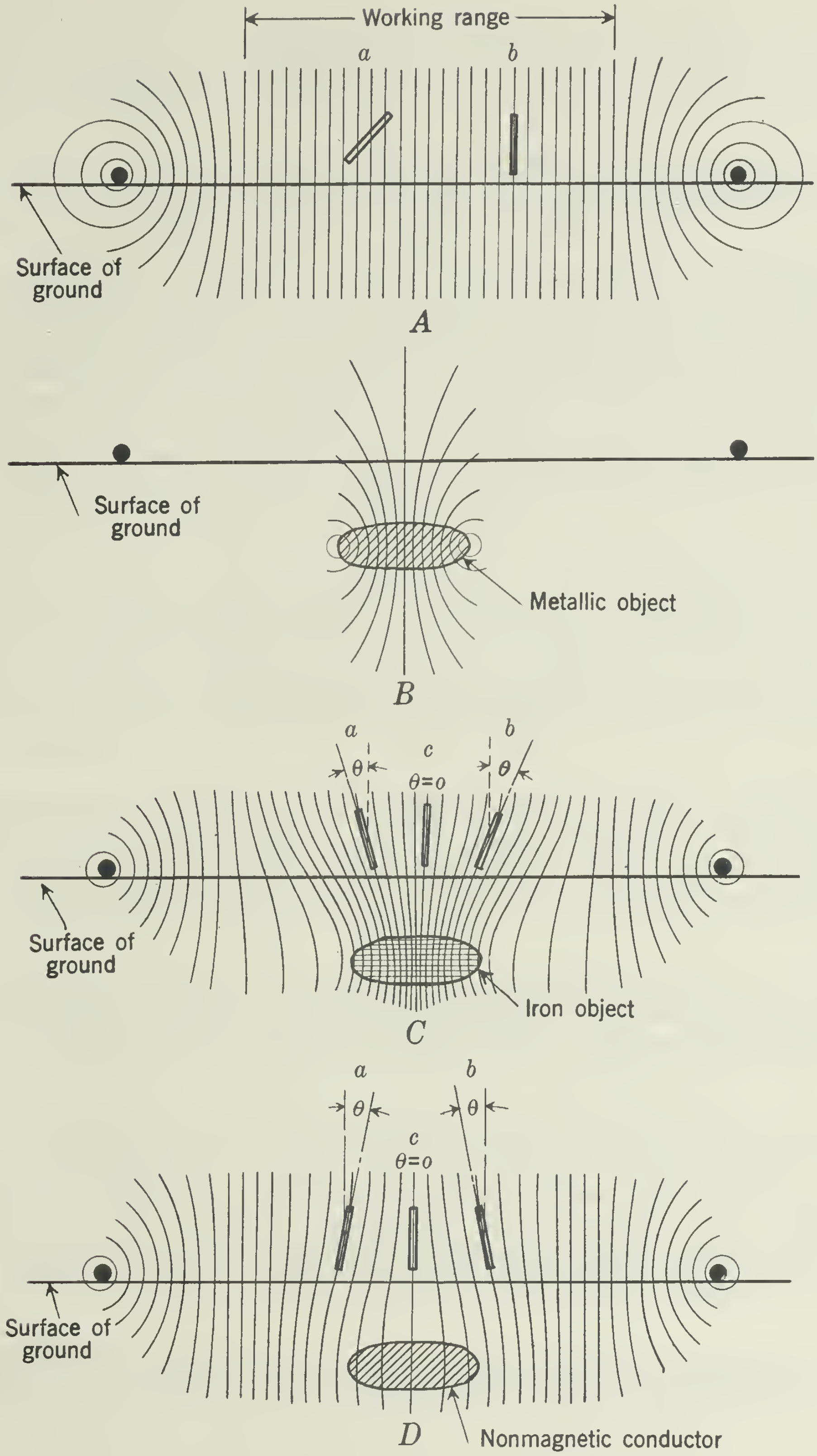

Figure 9.— Fixed exciting coil-movable pick-up coil.

any point in the area can be determined by observing the position of the search coil at which no voltage is generated in it, as evidenced by zero response from the detecting apparatus.

By keeping the search coil within 5 feet of the ground and never closer than 20 feet from the sides of the energizing coil the operator will avoid the curved portion of the primary field, as shown in figure 9,A.

Suppose, now, that a piece of iron is placed in the field. Immediately two phenomena occur. First the magnetic lines of force of the field are crowded into the specimen because of its high magnetic permeability. Second, eddy currents are generated because the iron is an electrical conductor being cut by magnetic lines of force. These secondary currents have associated with them a magnetic field (fig. 9,B) which is opposed to the primary field, so that the crowding of lines of force due to the high permeability of the iron is to a small extent offset by this second effect. The resultant distorted field is shown greatly exaggerated in figure 9,C.

If the search coil is moved across the area shown in figure 9,C, and the positions for zero voltage are observed an anomaly or irregularity will now be found over the iron, provided, of course, that a large enough quantity is present. As the buried object is approached the search coil will indicate that the field is flexed in toward the body on either side of it (positions a and b, fig. 9,C), while directly over it (position c) the field is again more or less vertical.

For a conducting body that contains no magnetic material the secondary currents alone produce the anomaly, and the primary field is forced away from the buried object, as indicated in figure 9,D. Here, again, the search coil detects the irregularity although in this instance the field bends away from the object.

In both instances cited the probable or apparent location of the buried object is the point at which the deflection angle of the search coil (θ) changes from one side of the vertical to the other. The entire region surrounding the object must be surveyed carefully to establish this point.

It must be understood clearly that this method is applicable only where a relatively large object is to be located in a rather limited area. It is extremely doubtful whether an iron object weighing less than 100 pounds or buried deeper than 4 feet could be found, and if the object is a nonmagnetic conductor even these limits are excessive for satisfactory detection. The methods that follow are far superior for detecting smaller objects and larger areas.

The merits of this method lie in the simplicity of the apparatus and the fact that once the power loop and generator are placed they need not be moved.

Mobile Exciting Coil-Balanced Pick-up Coils (Hughes Balanced Coils)

It is often inconvenient to use a stationary exciting coil, especially where large areas are to be investigated and the hunted object is small. Under such conditions one of the most effective methods is the so-called "Hughes balanced-coil" method.

A rigid frame is built on which are mounted an energizing coil and a system of pick-up coils. The latter are connected and placed in such positions that no secondary voltage will be generated when no metallic objects are present, but as soon as a conducting body is brought within range of the apparatus a measurable voltage is generated in the pick-up system. Such a condition may be realized in several ways.

For example, if two coils are made exactly alike in every detail each will have the same induced voltage if subjected to equal magnetic-field intensities. Now, if these two similar coils are placed at exactly equal distances on either side of an exciting coil (fig. 10) each will be cut by the same number of lines of force and consequently will have the same induced voltage. By connecting the two pick-up coils in series opposition the two induced voltages will just cancel each other, resulting in zero response in the detector.

If this coil assembly is placed over ground containing no conducting bodies the flux through each pick-up coil will remain the same (fig. 11,A), and no secondary voltage will be generated.

If, now, a magnetic conductor is present the magnetic flux from the exciting coil will be concentrated in the body, and an excess of flux will cut the lower coil, as represented by the shaded portion of the field in figure 11,B, so that its induced voltage is no longer balanced by that of the upper coil. Therefore a resultant secondary voltage will be generated, as evidenced by buzzing in the headphones. For a nonmagnetic conductor the primary field will be spread away from the object (fig. 11,C), resulting in an excess secondary voltage in the upper coil, as measured by the shaded portion of the field, and again giving rise to a resultant pick-up voltage causing a buzz in the headphones.

In theory it is necessary to carry such a device over the ground only until a signal is heard in the headphones, indicating the proximity of buried metal, which probably is located at the point where the loudest signal is heard.

In practice many difficulties and contingencies arise which must be circumvented before a reliable field outfit can be constructed. Some of these factors will now be discussed and ways of remedying them indicated.

It is essential that both pick-up coils be precisely alike in their physical dimensions and electrical properties. In winding these coils the wire must be wrapped in regular layers properly held in place so that the turns cannot shift their positions. Multilayer windings should be avoided as much as possible. In a single-layer winding capacity effects in the coils are reduced to a minimum. Where multilayer windings are used the capacities between windings become quite large and are not always equal for two coils, even though the coils have the

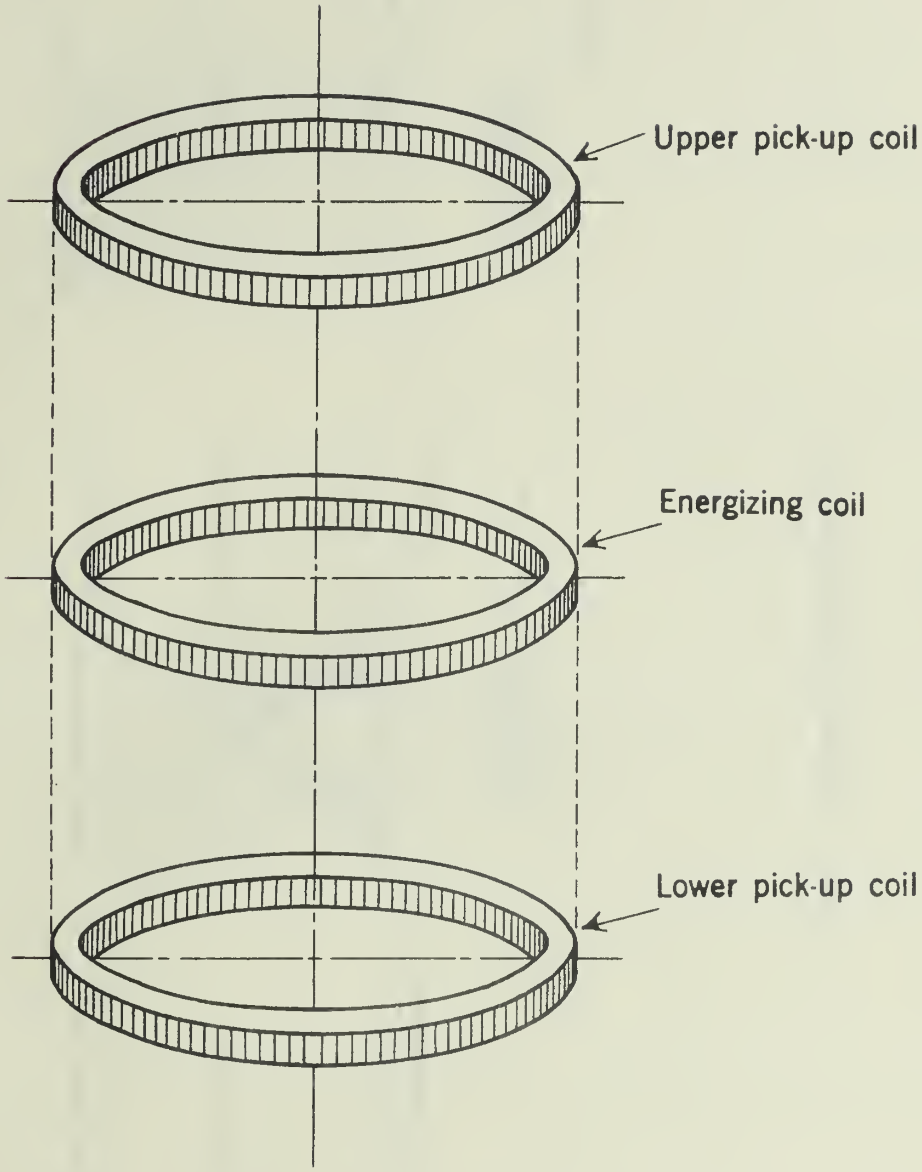

Figure 10.—Movable exciting coil and balanced pick-up-coil arrangement.

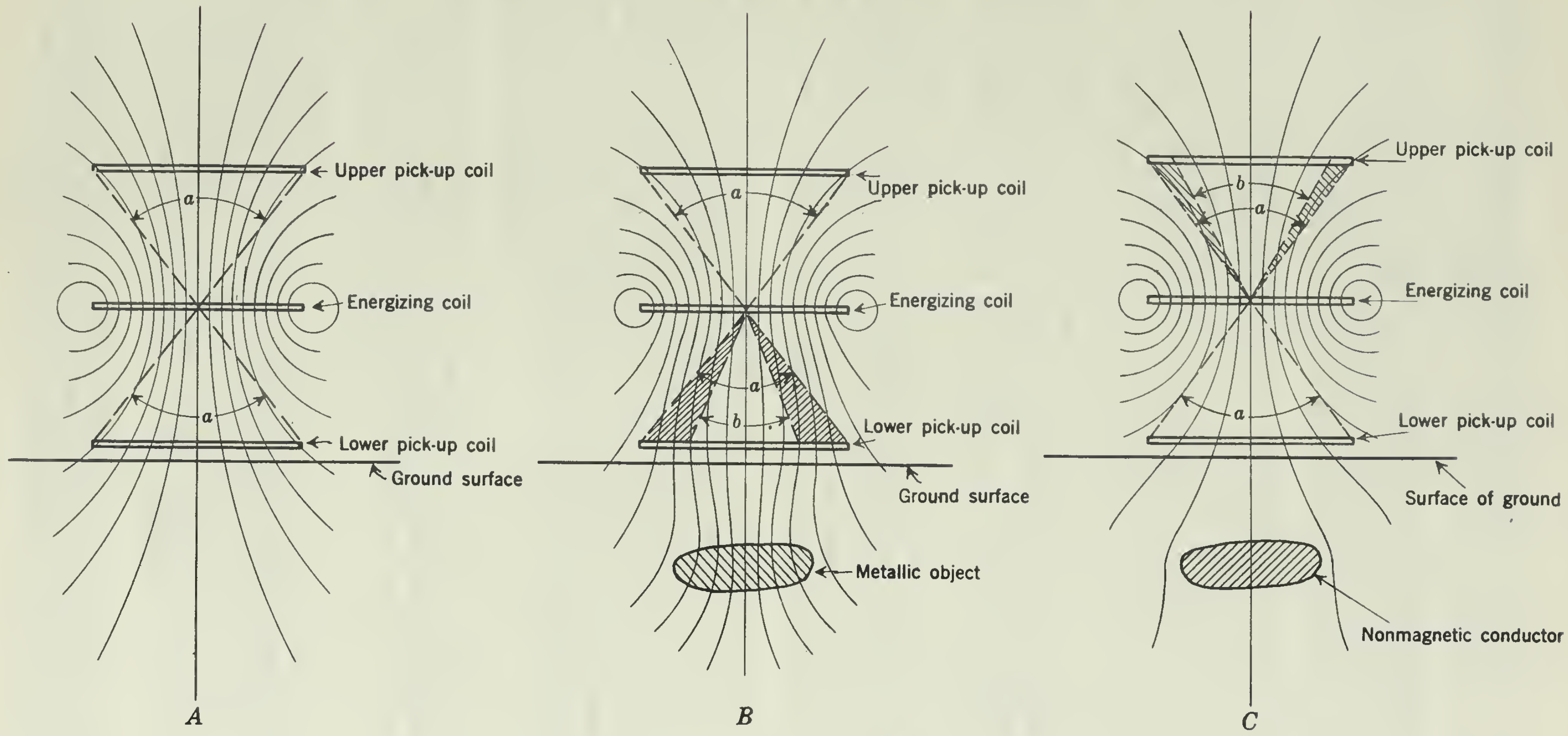

Figure 11.—Balanced pick-up-coil method.

same number of turns and physical dimensions. In such a case it is impossible to obtain a balance between the two secondary voltages by any simple method.

The primary coil should be wound in a regular manner, and a single-layer coil should be used for the higher frequencies. Primary and secondary coils should also be far enough apart to avoid any appreciable capacity coupling from one to the other; a 6-inch separation ordinarily should suffice.

Another important point in the construction of the apparatus is to mount the coils in their proper positions so that they remain absolutely stationary relative to each other despite any ordinary shocks the apparatus may receive while in use. The carrying handles must be fastened to the coil assembly so that it will not flex while being carried, as such motion will cause the coil spacing to shift and occasion an erroneous signal in the detector.

For small coil assemblies the most satisfactory system of mounting is to wind all three coils on a single cylindrical form, suspending the latter from the carrying handles by a rope cradle. For larger outfits a rather elaborate system of internal bracing is necessary to insure rigidity.

No screws, nails, or any other bits of metal aside from the wire in the coils, should be used in the entire assembly. The coil forms and bracing should be made of well-seasoned wood held together with wooden pegs and glue. The presence of any metal results in local secondary circuits which make it difficult or even impossible to balance the two secondary pick-up-coil voltages accurately.

All coil leads must be twisted and fastened securely to the coil form to prevent them from swinging while the apparatus is being carried. Any motion of the coil leads results in disturbing induced voltages in the pick-up system. These, however, will be small for twisted leads, but for satisfactory operation they must be avoided. The generator and detector leads should be supported for a distance of 2 or 3 feet from the coil assembly by radial arms fastened to the frame. The operator wearing the headphones must be at least 20 feet from the coil assembly to prevent an audible reaction of the primary field on his headphones.

After the coil frame is assembled, a slight, final adjustment of the pick-up-coil windings usually is necessary to make the voltages in each absolutely equal. This is done by adding or subtracting turns on one of the coils until no signal is heard in the detector.

No definite limits of the sensitivity of this method can be given from a theoretical basis. Among the factors influencing sensitivity are size, shape, and composition of the buried object; character of material in which it lies; size, number of turns, and separation of the pick-up coils; size, number of turns, and current in the primary coil; degree of amplification of the pick-up-coil voltage; and sensitivity of the detector.

The larger the ratio between pick-up-coil separation and diameter and the larger the coils themselves the greater the sensitivity. Weight and awkwardness in handling impose practical limitations on the size of the apparatus used,

since it must be portable. Coils larger than 3 feet in diameter are unwieldy, and a separation of 4 or 5 feet between pick-up coils should not be exceeded.

Figure 12 shows the electrical connections for balanced pick-up-coil methods. Figure 12,A, shows the simplest possible connection, comprising the generator, coils, and headphone detector. In figure 12,B, the sensitivity has been increased by resonating all coils and adding a secondary-voltage amplifier. As the degree of amplification is increased, more and more difficulty is encountered in obtaining an accurate secondary-voltage balance, until a point is finally reached where "background" noises in the amplifiers begin to interfere seriously with the observations. The experimenter must exercise good judgment in determining the amplification necessary for optimum results.

As an actual example of the use of this method to locate buried metallic objects, the following information taken from a report by Dr. T. Theodorsen, of the National Advisory Committee for Aeronautics,[3] is given.

A single form was used for all three coils, as shown in figure 13. The windings were wrapped in single layers, and the primary coil was supplied with 1 ampere from a small portable generator having a frequency of 500 cycles per second. The head phones used as the detector were rewound so that their impedance equaled that of the pick-up coils in series. No resonating condensers or pick-up-voltage amplifiers were used.

The entire coil assembly was held together with wooden pegs and glue, the only metal being the wire itself.

With this apparatus masses of steel weighing approximately 17 pounds were detected at depths up to 2 feet below the surface. This range proved ample for the particular problem for which the apparatus was designed and doubtless could be increased by resonating all coils and amplifying the pick-up voltage.

In conclusion, this method of induction prospecting has the advantages of portability and speed, so that relatively large areas may be covered rapidly. It is well-suited to the findings of small metallic objects relatively close to the surface. On the other hand, a skilled operator is needed if reliable results are to be obtained, and great care must be taken in the construction and adjustment of the apparatus to insure satisfactory operation.

Mobile Exciting Coil-Single Pick-up Coil

It is possible to place a single pick-up coil in such a position relative to an exciting coil that when no conducting bodies are present no voltage will be generated in the pick-up coil. On the other hand, the presence of a metallic object near the assembly will distort the magnetic field of the energizing coil and cause an induced voltage in the pick-up coil.

3/ Theodorsen, Theodore, Instrument for Detecting Metallic Bodies Buried in the Earth: Jour. Franklin Inst., vol. 210, 1930, pp. 311-326.

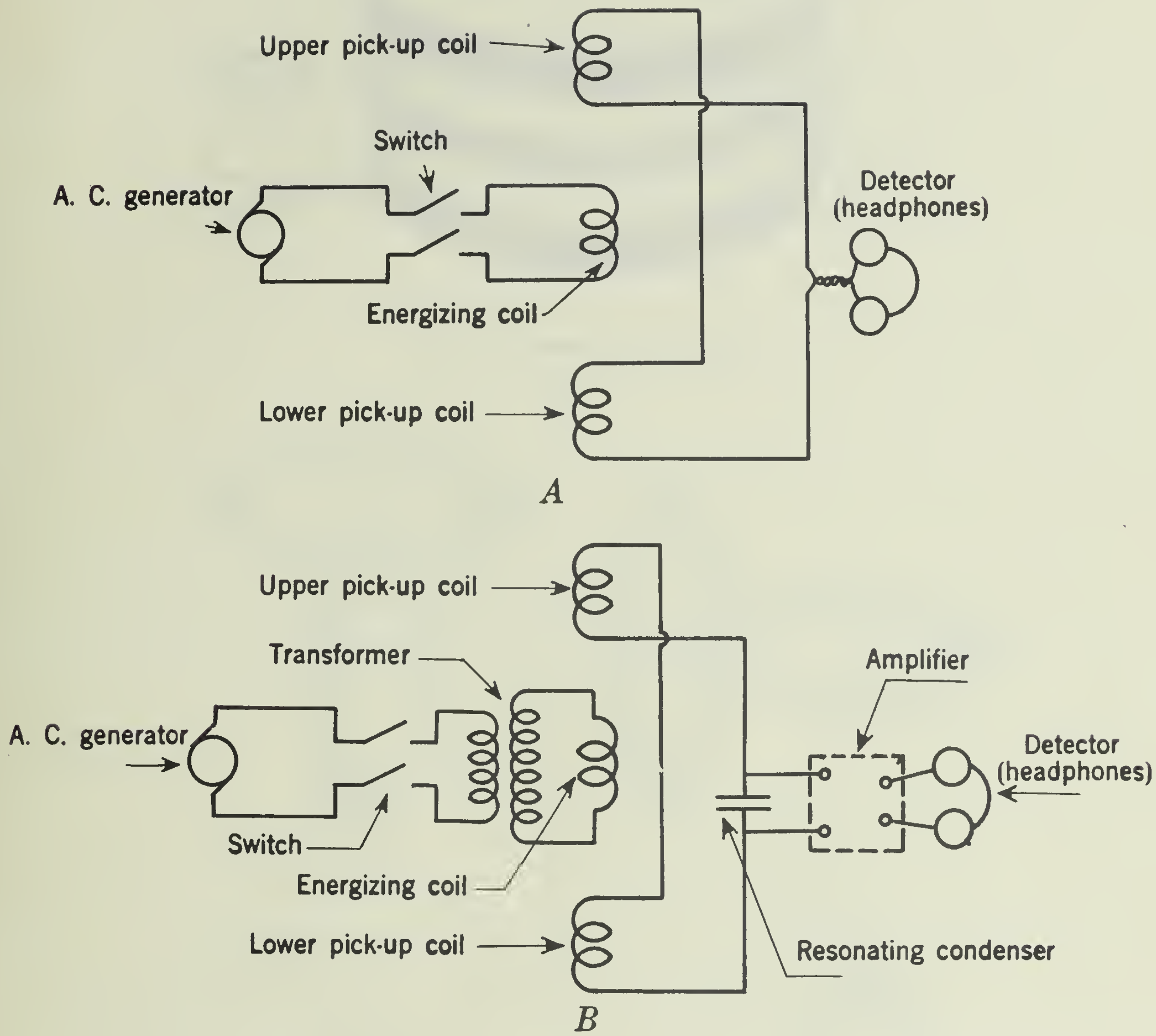

Figure 12.— Electrical connections for balanced pick-up-coil methods.

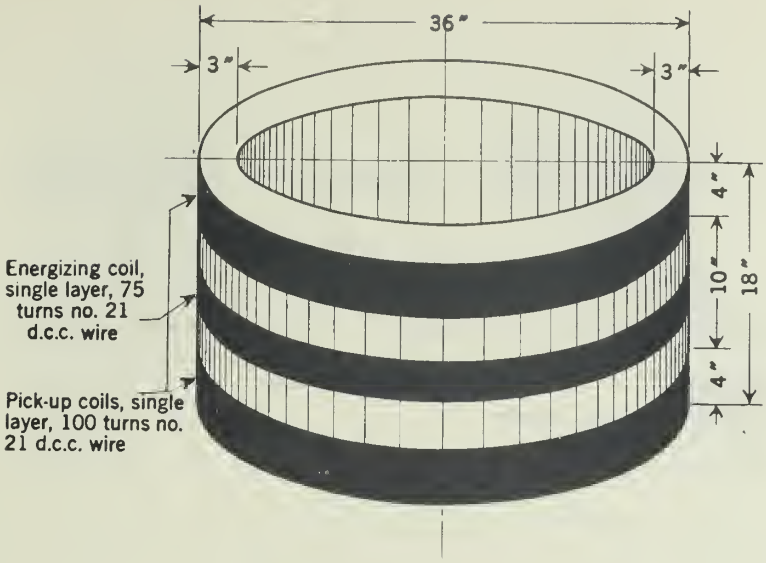

Figure 13.—Theodorsen's coil assembly.

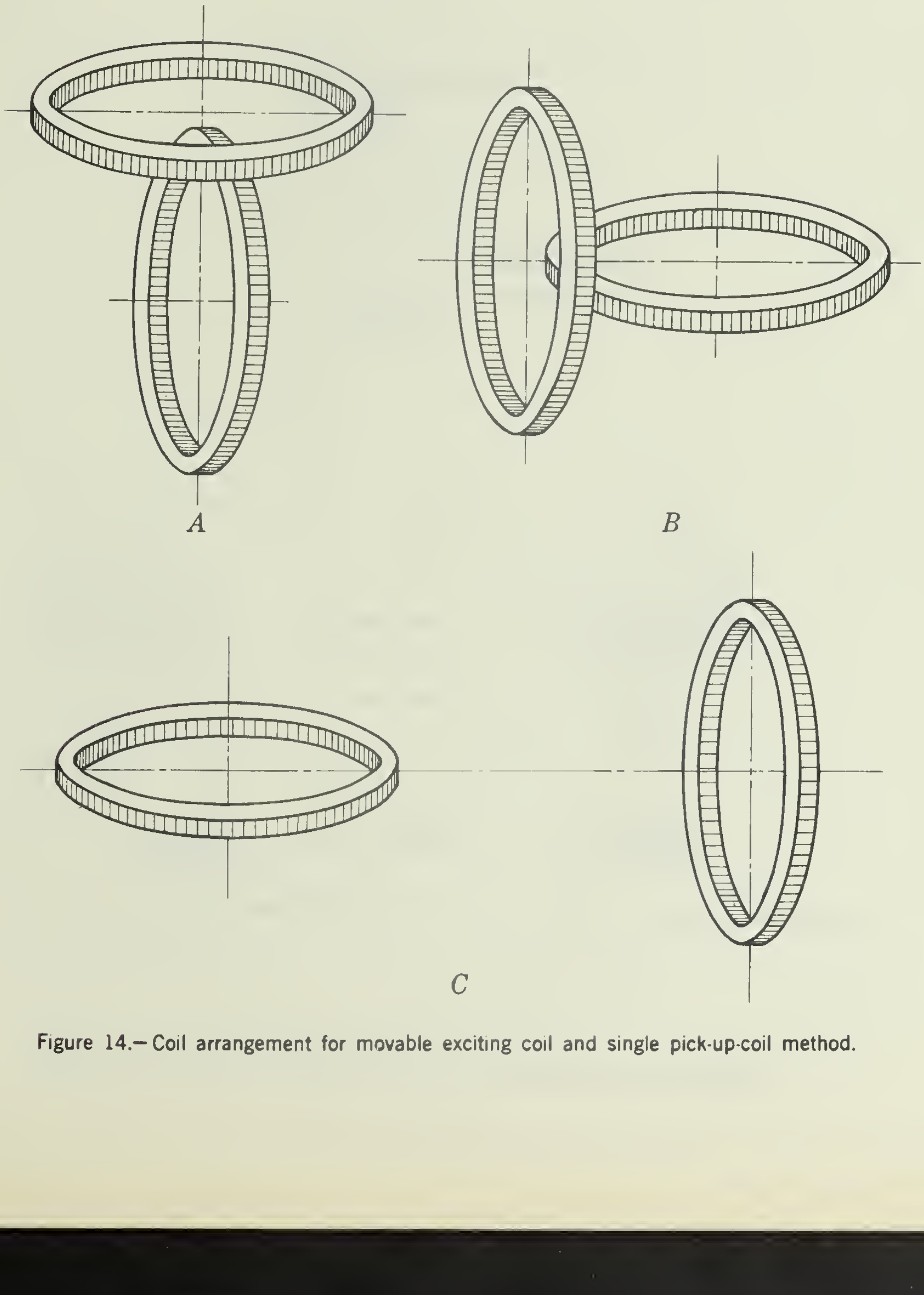

Figure 14.—Coil arrangement for movable exciting coil and single pick-up-coil method.

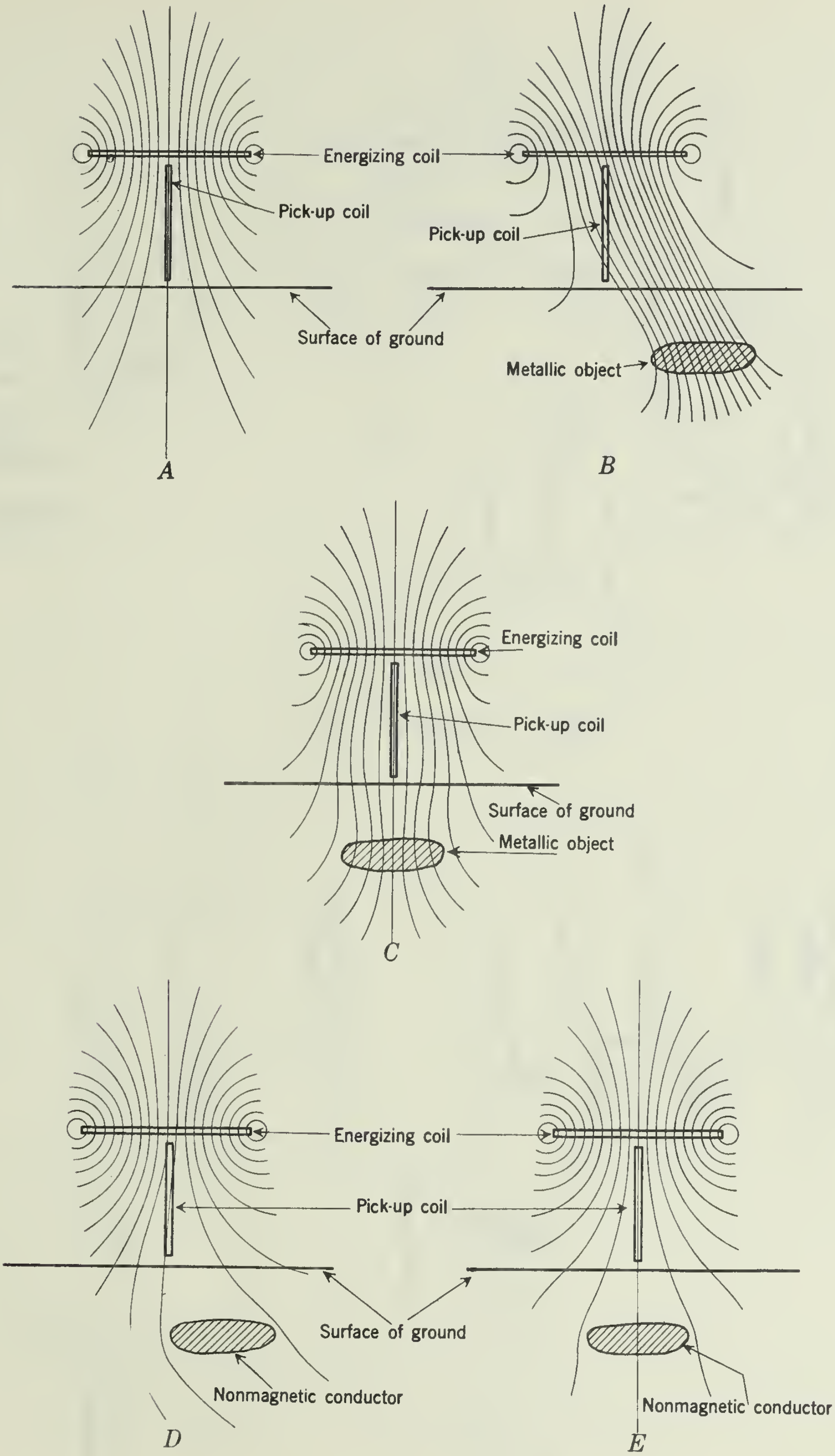

Figure 15.—Movable exciting coil and single pick-up-coil method.

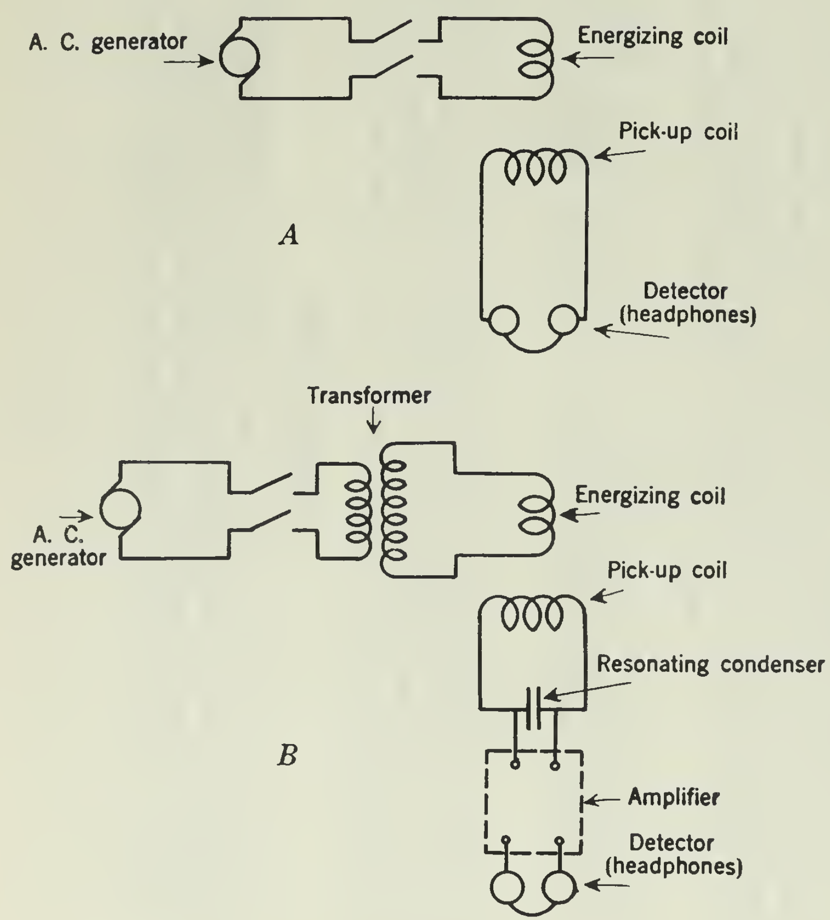

Figure 16.— Electrical connections for movable exciting coil and single pick-up-coil method.

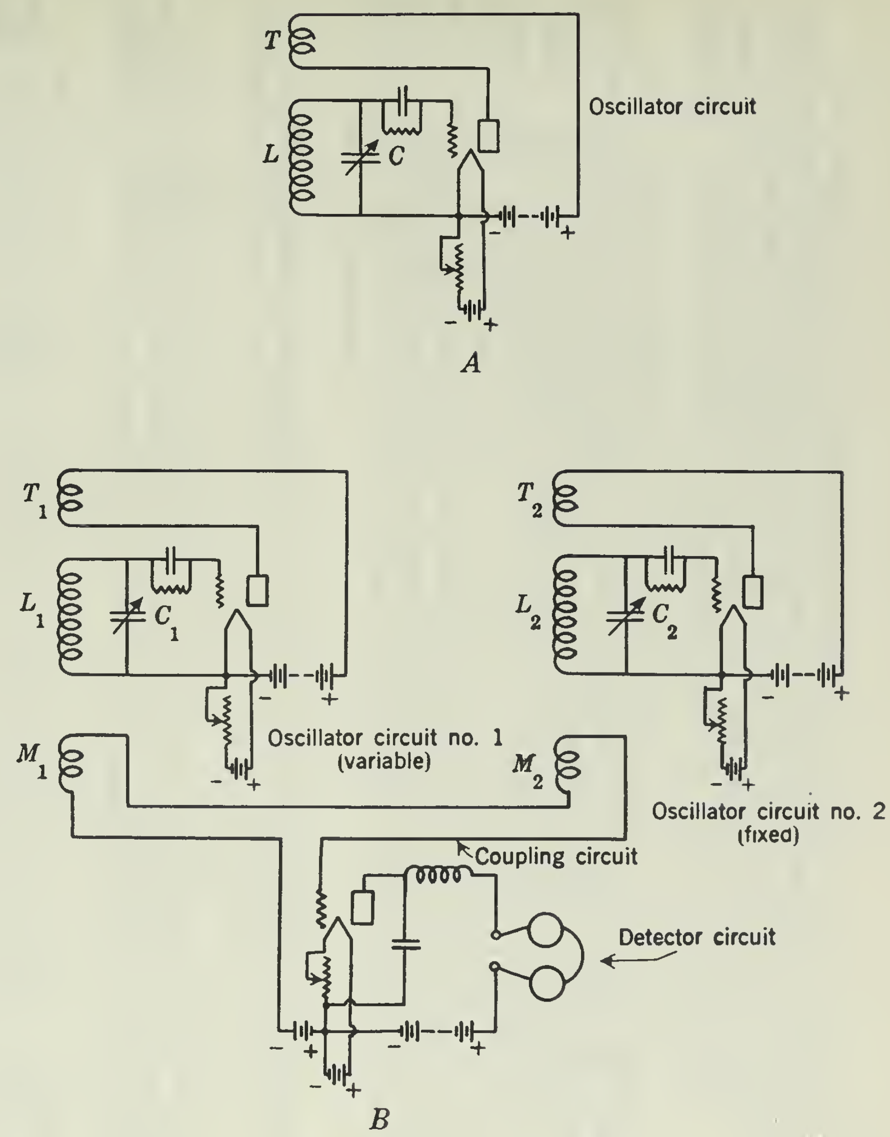

Figure 17.— Electrical circuits for beat-frequency method.

The conditions cited above are fulfilled when the axis of one coil intersects perpendicularly that of the second coil at its center. Two examples of such an arrangement are shown in figure 14,A and B. In figure 14,C, the distance between the coils has been increased, but the same result is obtained. Moreover, either coil may be the exciting coil in such an arrangement.

For example, consider the coil arrangement given in figure 14,A, in which the exciting coil is horizontal. Then, as shown in figure 15,A, no lines of force pass through the pick-up coil, and consequently no voltage will be induced. Now, if the assembly approaches a metallic object of high magnetic permeability the field will be distorted, as shown in figure 15,B, and the magnetic lines of force will induce a voltage in the pick-up coils. If a nonmagnetic conductor is approached the field is distorted, as shown in figure 15,C, again resulting in a secondary voltage. Directly over the metallic bodies the field again parallels the plane of the pick-up coil (fig. 15,D), and no secondary voltage is generated.

By this method the presence of a buried metallic object is indicated by a signal on either side of the body, but no signal directly over it.

The electrical connections for this scheme of prospecting are shown in figure 16. The simplest arrangement is given in figure 16,A, and the most sensitive, involving resonated coils and signal amplification, in figure 16,B.

As with the balanced pick-up-coil system, numerous practical features must be considered before a successful field outfit can be built. The coils must be supported rigidly in position, and the windings should be in even layers. Single-layer coils are not essential, as with the balanced pick-up-coil method. As in the previous case, generator and pick-up-coil leads must be twisted and supported carefully, and the operator using the headphones should be 20 or more feet away from the coil assembly. No nails or other metal should be used in the coil forms and mounting frame.

In designing the coil frame it is advantageous to mount the pick-up coil so that its position relative to the energizing coil can be shifted about until, with no metallic objects present, no signal is heard. The pick-up coil should then be clamped firmly in place.

The advantages and disadvantages listed for the balanced pick-up-coil system apply equally well here. An additional favorable feature is the decrease in weight of the apparatus as a result of the elimination of one pick-up coil. The effective range probably is less than that of the balanced pick-up coils.

Beat Circuits

If a conducting body is brought near a coil carrying an alternating current the self-inductance of the coil will be reduced if the conductor is nonmagnetic and increased if it is magnetic. This simple fact is utilized in a method of prospecting which can be called the "beat-frequency" method.

Consider the elementary oscillator shown in figure 17,A. The frequency of oscillation of this circuit is determined by the effective inductance of coil L and the capacity of condenser C. If a metallic object is now brought near L the self-inductance of the latter will be altered, and since C remains constant the frequency of oscillation will change. To observe this change to the best advantage a fixed oscillator is used as a reference frequency. It is set to a frequency equal to that of the test oscillator when no metallic body is near coil L and is shielded completely so that metallic objects nearby do not alter its frequency. Both oscillators are then coupled loosely to a detector circuit (fig. 17,B).

Coil L_1 of the test oscillator usually is wound on a large wooden form mounted on a carrying frame so that it may be moved along close to the surface of the ground. Practical details of the apparatus are included in a later section.

In operating this device search coil L_1 is held over a section of ground known to be free from metallic objects, and tuning condenser C_2 of the fixed oscillator (fig. 17,B) is adjusted until either a very low pitched note or no note at all is heard in the detector headphones. Coil L_1 is then moved over the ground, and as it approaches a metallic object the pitch of the beat note in the headphones changes. This note reaches the maximum difference of pitch at the point of nearest approach to the buried object.

In 1933 Dr. E. V. Potter, of the United States Bureau of Mines, conducted a series of preliminary investigations of this method. The actual circuits used are given in figure 18, and the details of the various coils are shown in figure 19.

It should be understood that the circuit constants given are not necessarily those recommended for prospecting. This circuit was used in the first test work, and subsequent results may justify alterations.

The first step in the design of the apparatus was the selection of the oscillator frequency, that is, the values of L_1, L_2, C_1, and C_2. This choice was governed by the facts that (1) the ground acts as a shield to the magnetic field of coil L_1 and (2) the shielding effect increases greatly with frequency - the higher the frequency the more effectively can be measured the change in inductance L_1 caused by the proximity of a metallic object, that is, the greater the range of the outfit. It was decided to investigate several frequencies in an attempt to establish experimentally the optimum value; accordingly, the circuits were arranged to cover a range of 1,000 to 2,000 kilocycles per second (1 kilocycle = 1,000 cycles). Changes were accomplished by altering the variable capacities C_1 and C_2 (fig. 18). As shown in the figure, C_2 comprises three condensers in multiple. Coarse adjustments were made with the 500- and 32-$\mu\mu$f (micromicrofarad) units and the final fine-setting with the 4-$\mu\mu$f unit.

When first assembled the two oscillators were unsteady in operation, and their frequencies shifted, causing the pitch of the note in the headphones to alter even when the apparatus was stationary. Most of this unsteadiness vanished after about an hour's operation, owing largely to a steadying of battery voltages

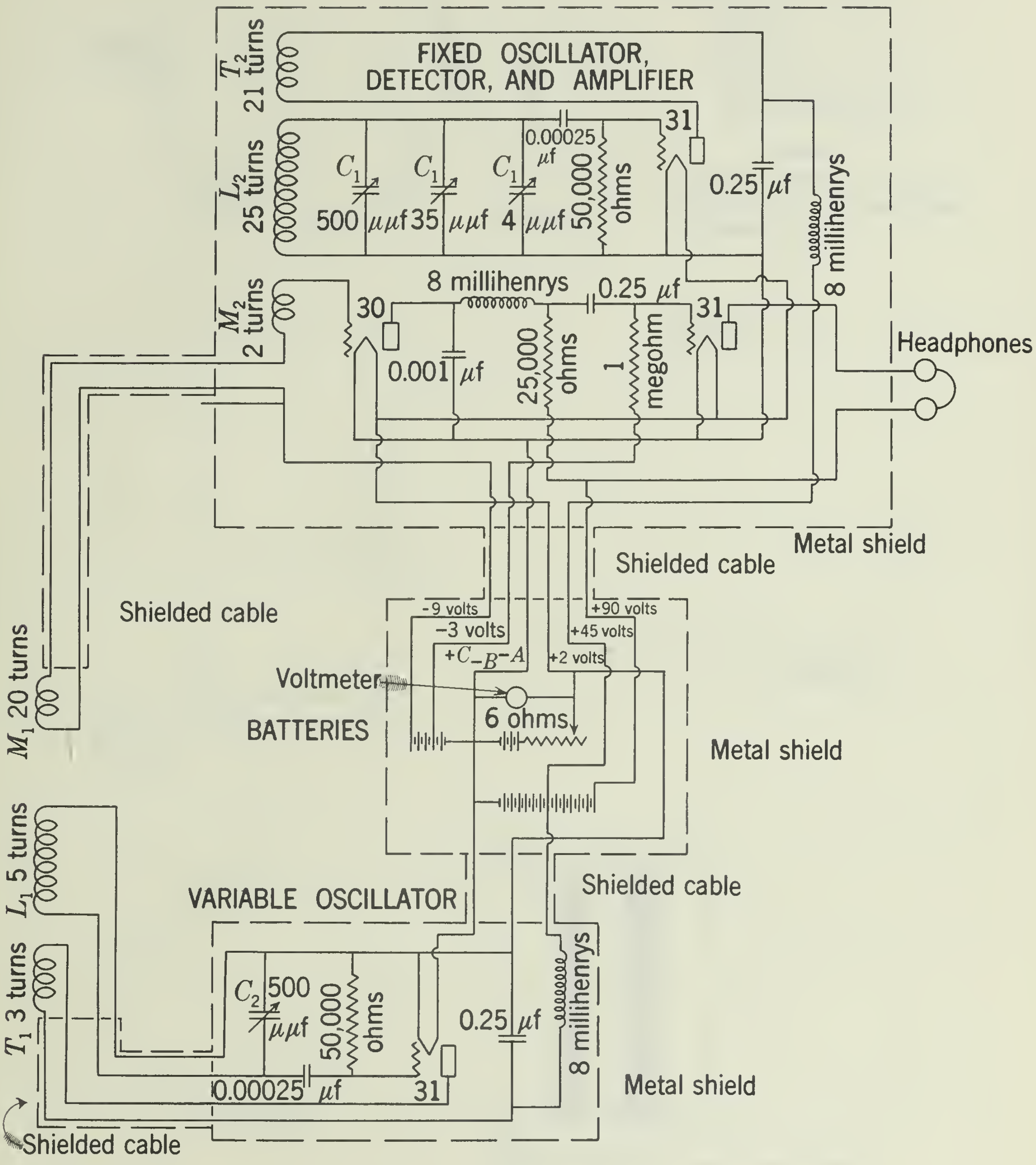

Figure 18.—Fixed oscillator, detector, and amplifier, batteries, and variable oscillator.

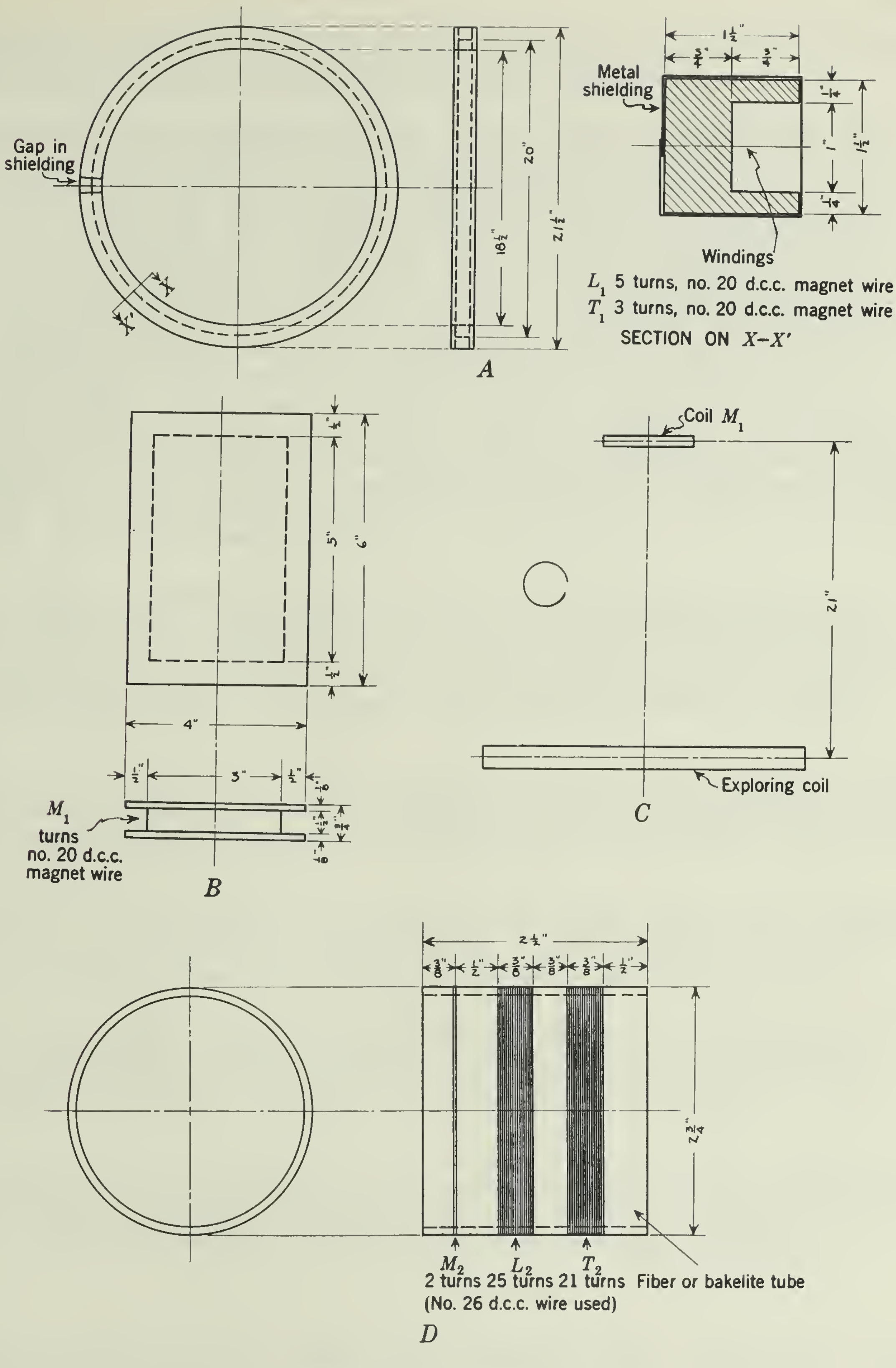

Figure 19.—*A*, Dimensions of L_1 and T_1 exploring coils; *B*, dimensions of M_1; *C*, relative positions of exploring coil (L_1 and T_1) and M_1; *D*, dimensions of M_2, L_2, and T_2.

and the thorough heating of the vacuum tubes. Dry cells were not stable enough sources of filament current, so storage cells were substituted.

In the field tests a periodic change in the pitch of the headphone note was observed as coil L_1 was moved along the ground. This apparently is due to the change in capacity from coil to ground, which in turn is due to the varying distance between coil and the ground surface as the operators walk along with the coil. To reduce this effect the exploring coil was carefully shielded electrostatically, as shown in figure 19. The coil was enclosed in a metal wrapping except for an interval of an inch or so at one point. This gap was left to prevent the shield from forming a complete electrical circuit; in that instance secondary currents would be generated and would act as an electromagnetic shield as well. This must be avoided, as the electromagnetic effect causes the frequency of the test oscillator to change as metallic objects are approached. If shielding the coil does not remove the ground to coil-capacity effect entirely a lower oscillator frequency can be used; indeed, the results of Dr. Potter's work indicate that frequencies below 1,000 kilocycles per second probably would give better results. No opportunity for further experimental work on this question has been available.

Mounting the equipment on wheels or skids so that it can be dragged over the ground to keep the distance between coil and earth surface more or less constant should improve operations. Also, the oscillators should be carefully cushioned on sponge rubber to avoid shocks arising from the movement of the device being transmitted to the vacuum tubes or tuning condensers, as they would alter the oscillator frequency.

Variations in the detector note also were traced to slight deformations of the coil form or displacements of the battery and other connecting leads. These conditions were remedied by increasing the rigidity of the assembly and carefully fastening all wires in place.

Exception for exploring coil $\underline{L_1}$ and detector pick-up $\underline{M_1}$ (fig. 18), all electrical circuits and batteries were shielded in grounded metal boxes, and battery leads and other connections were carried in grounded, lead-sheath cables.

Using the equipment indicated in figures 18 and 19, an empty 5-gallon oil can could be detected 30 inches from the coil in air and about 15 inches beneath the surface of the ground, with the exploring coil 8 inches above the surface. These ranges were decreased when a smaller can was used.

An account of the construction of a "treasure" finder based on the foregoing principles is given in the July 1933 issue of Radiocraft.[4] In all probability the average builder will hardly realize the range of detection given in the article, but nevertheless, the outfit is no doubt quite sensitive.

4/ Sarver, E. Franklin, How to Build a New Treasure Finder: Radiocraft, vol. 5, July 1933, pp. 8-10.

It must be emphasized that in constructing the oscillators only the best grade of parts should be used. Poor-quality equipment always introduces difficulties, especially in the stability of the oscillators, and stability is of primary importance in this method.

Although still more or less in the experimental stage, this method appears to have possibilities. It is rapid and has a sensitivity or range of detection as good or possibly better than any of the other schemes. Moreover, energy is supplied by batteries through the medium of oscillating circuits, making a generator unnecessary. Two men can operate it, and the cost of construction of the apparatus itself is relatively small.

The greatest disadvantage is the fact that a skillful, scientifically trained man is required to construct and operate the device. Manipulation of the circuits and the fact that weak batteries and tubes cause difficulties require a man familiar with such work for satisfactory results.

Miscellaneous Induction Problems

The various induction methods of prospecting discussed in the foregoing sections of this report are applicable to the general case of finding buried conductors. Certain specific problems, however, are handled more readily by special technic. The location of buried metal pipes falls in this category.

Consider a cross-section of ground in which a metal pipe line is buried (fig. 20). If an alternating electric current is passed along this pipe the resulting magnetic field will be concentric, as shown in the figure. If a small pick-up coil is placed in a horizontal position in such a field induced voltages will be generated for all positions of the coil except directly over the pipe (B, fig. 20). In this position the field parallels the plane of the coil, does not cut the latter, and hence generates no voltage. As a result, the detector indicates zero (that is, silence) if headphones are used.

In practice the best arrangement is to use an alternating current of 500 cycles per second frequency and to connect a pair of headphones directly across the pick-up-coil terminals or to an amplifier if one is used to obtain enough sensitivity for the particular problem at hand. With the pick-up coil held horizontally the operator walks over the ground until he reaches a point of silence. The point is then directly over the buried pipe line.

Means of electrifying the pipe will now be discussed. If both ends of the line are available a generator lead is clipped to each end, as shown in figure 21,A, and the pipe becomes an integral part of the electrical circuit. When only one end can be located a generator lead is clipped to that end, and the other is connected to an iron stake. The stake is then driven into the ground in an area over the supposed course of the pipe. The current flows along the pipe and out into the ground to the iron stake, as shown in figure 21,B. When neither end of the pipe line can be reached two stakes are connected to the generator and driven into the ground several hundred feet apart along the suspected path of the pipe (fig. 21,C). Current then flows into the ground from one stake and as the metal pipe is a good conductor tends to concentrate along the pipe, leaving it finally to enter the second stake.

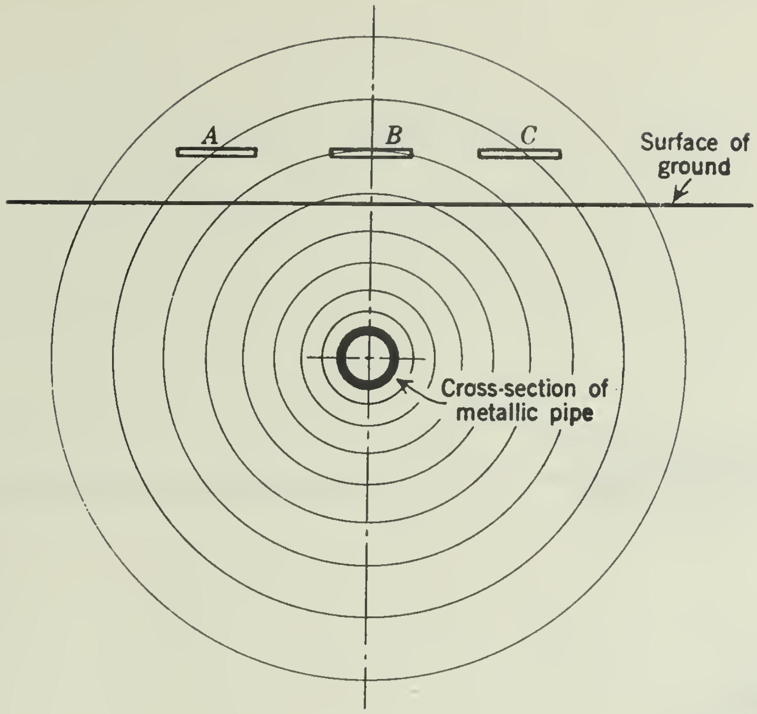

Figure 20.— Location of buried metal pipes.

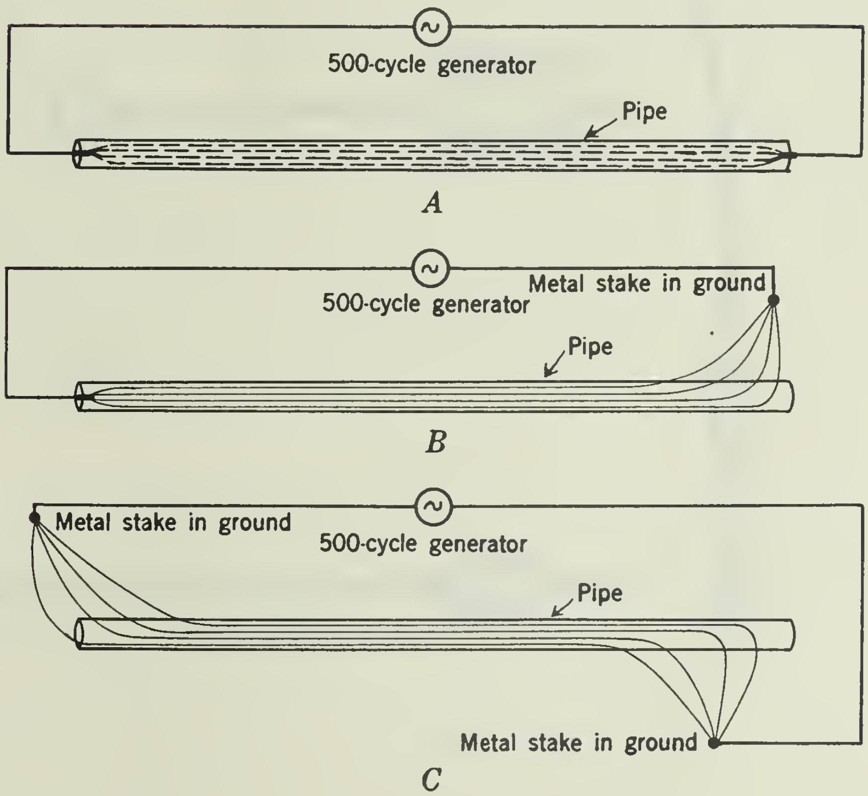

Figure 21.— Energizing buried metal pipes.

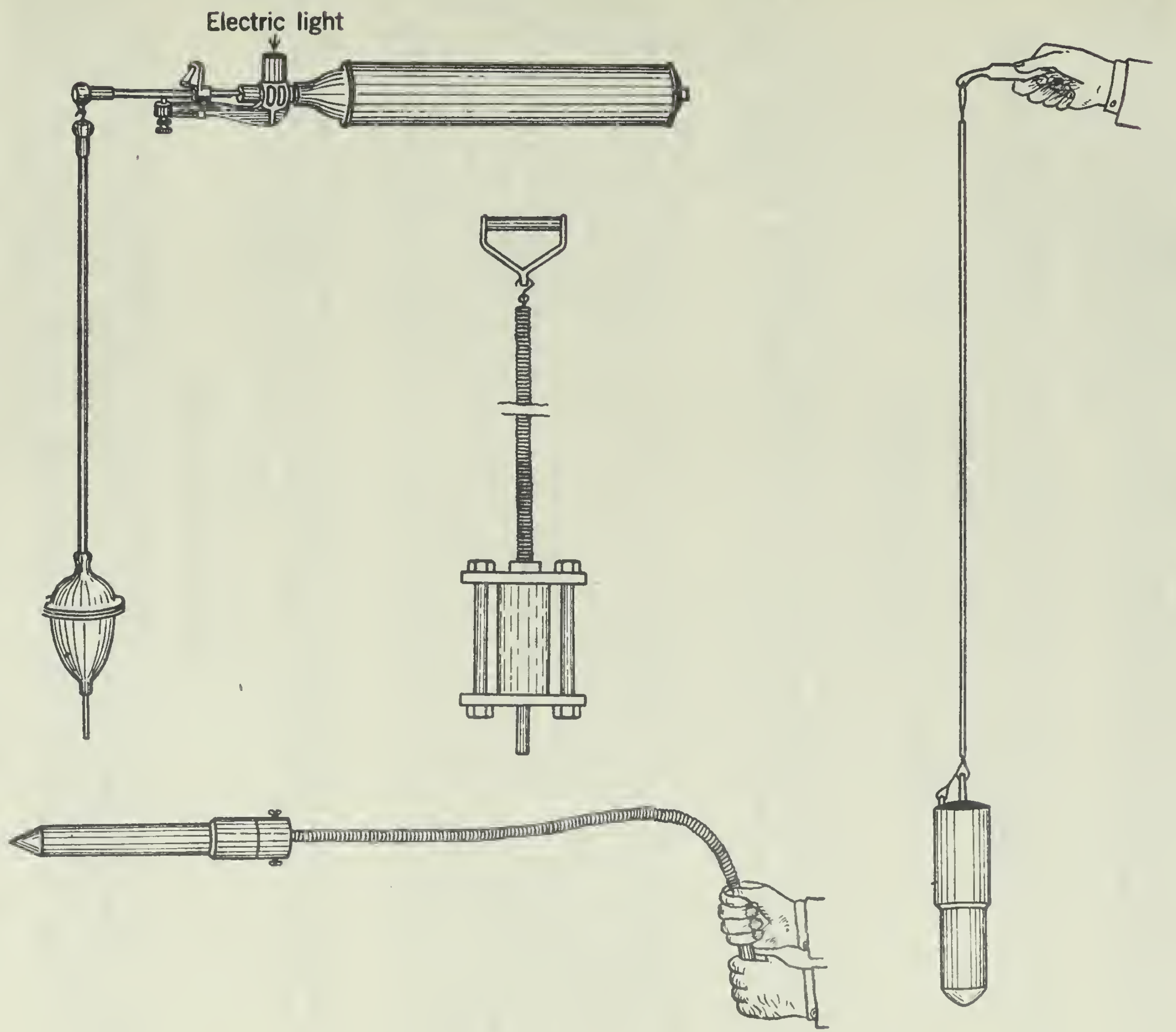

Figure 22.– Devices without scientific foundation

As soon as the true position of the pipe line is indicated the iron stakes are moved so that they are more nearly over the pipe, the ideal location. Quite definite results thus may be realized.

Nonmetallic pipes cannot be located, as they are not electrical conductors. However, if both ends of the line can be reached and a metal wire can be worked through from one to the other and connected across the generator, the course of the pipe line may be traced.

Where short lengths of metal pipe - 15 feet or less - are to be located the general induction methods are better suited to the problem.

METHODS WITHOUT SCIENTIFIC FOUNDATION

The Divining Rod

The divining rod is the oldest of all "doodle bugs." It is mentioned in the literature for mineral exploration as early as the sixteenth century. This rod has been used in attempts to prospect minerals, treasures, water, and a host of other things.

Today the major claim made for the divining rod is that it can find water. In this capacity there are on record a few apparently well-authenticated cases of successful work, but in virtually all of these the operator was either a skilled geologist or hydrologist, and his scientific knowledge undoubtedly played an important role in his successes. In an attempt to explain its operation it has been suggested that the divining rod acts as an indicator, registering the nerve reactions of the operator, and that in some unknown manner these reactions are experienced by certain people in the vicinity of water. Such an explanation is obviously nebulous but points to the fields of physiology and psychology in addition to that of physics for its explanation, if there is any real basis for it.

No scientific ground for the operation of the divining rod is known at present, and certainly no well-informed person should risk any investment on the basis of divining-rod indications.

Fraudulent Apparatus

Self-deluded fanatics and unscrupulous individuals have offered to the public so-called treasure-finding apparatus of a wholly fradulent nature, absolutely devoid of any scientific basis. All manner of claims are made for these devices, including their ability to find oil, gas, minerals of all kinds, lost coins and treasures, buried pipes, and water.

Claims are made that operation of some of these devices is based upon "mineral vibrations". They lead one to believe that each mineral emits a unique and characteristic vibration which may be detected, disclosing the location and kind of minerals present in the ground. Scientists have not discovered any such "mineral vibrations". Radio-active elements give rise to spontaneous emanations

of gamma rays, and the various elements when properly excited by greatly increasing their temperature emit their characteristic spectra; these phenomena, however, are entirely apart from those implied by the unscientific term "mineral vibrations".

The public is advised to carefully investigate all schemes and apparatus for which extravagant claims are made before expending any money on them.

CONCLUSION

The purpose of this paper is to describe in a general way scientifically sound methods of finding small buried metallic objects and to point out the limitations to their useful application.

It must be emphasized that at best the location of small amounts of metal is difficult, especially when nonmagnetic, as, for example, gold and silver. The location of small nonmetallic objects by the methods described is impossible.

Finally, if the best results are to be realized scientific training and experience are indispensable. Unfortunately, treasure finders have not reached the point of perfection where they can be operated indiscriminately by anyone of average ability, as is true of radios, automobiles, and similar commercial products. Treasure finders for commercial use are still in the first stages of development; as with all experimental devices, unforseen conditions and difficulties are continually arising, the solution of which requires the services of an experienced research man. The reader must realize these facts; otherwise he is doomed to disappointment in his search for hidden wealth. In general, it is wiser to employ the services of reliable individuals or companies already experienced in and equipped for such work.

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ACCIDENT COSTS AND SAFETY DIVIDENDS

BY

D. HARRINGTON

I.C. 6855,
December 1935

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

ACCIDENT COSTS AND SAFETY DIVIDENDS[1]

By D. Harrington[2]

INTRODUCTION

In general, mining is carried on underground, that is, in confined places where it is difficult to obtain adequate lighting and frequently in rock strata requiring much care to prevent caving. Moreover, explosives must be used in mining with the numerous hazards associated with them, and some mines give off explosive or irrespirable gases; also, machinery must be used, usually under conditions much more hazardous than on the surface. These and many other considerations cause mining to be probably the most hazardous occupation in which large numbers of our fellow countrymen are employed.

Prevention of accidents in the mining industry is far more complicated than in surface industrial work, even of the more hazardous types, because the different elements that enter into possible accident occurrence are ascertained more readily above ground and suitable action can be taken against them; moreover, errors in connection with prevention of accidents in surface industrial work usually affect only one or, possibly, a few persons, while in mines one human error may readily cause an explosion or other untoward occurrence resulting in the death of scores or even hundreds of persons.

This difficulty in the prevention of accidents in and around mines is well-known, and most countries and States have regulations to guard the safety and, to a much smaller extent, the health of workers in mining and allied industries. In general, the State laws and regulations regarding the welfare of mine workers are merely a skeletonized outline of some more or less fundamental minimum requirements and are far too general to do much more than suggest some procedure which may or may not be safe or healthful. Most of them are grotesquely out-of-date as applied to present-day conditions, and none of them is adequate to protect life, limb, health, or property.

Unquestionably, there is great need for a closer correlation of the laws and regulations of the various States with regard to safety in the mining and allied industries, and while mining conditions vary far too much for a standardized mine safety law applicable to all of the States, on the other hand there are numerous standard and fairly fundamental safety provisions which apply to all mines and which should be embodied in the mining codes of all States. Undoubtedly, these standardized safety requirements would be opposed by a considerable part of the industry, but the ultimate effect would be beneficial to the owners, workers, and the general public.

For many years progressive mining companies in the United States have not been satisfied to operate only within the meager safety requirements of the State laws or regulations and have adopted additional and far more effective safety procedure of their own, although complying also with the State laws and regulations. As a result of this forward-locking policy, many of these companies have made astonishing progress in the reduction of accidents. This

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2 Chief, Health and Safety Branch, U.S. Bureau of Mines, Washington, D.C.

is true of bituminous-coal and anthracite mines; metal mines; nonmetallic mineral mines; coking plants; milling, smelting, and metallurgical establishments; and the various activities in connection with the production and processing of petroleum. Some mines have worked 25 or more years without a fatal accident; others have worked with a considerable number of men a year or more without a lost-time accident. One surface mining operation produced upward of 75,000,000 tons of rock without a fatality, another underground mine produced over 15,000,000 tons of ore without a fatality, and numerous individuals have worked 50 or more years in mines without having sustained any accident which would prevent their working at their own job on the next regular shift.

That considerable progress has been made in the prevention of accidents in the mines of the United States is not generally known, and a few figures will doubtless be illuminating. At various times in the past most persons remember having read headlines in the daily press calling attention to some terrible mining disaster; fortunately, affairs of this kind are now few and far between.

ACKNOWLEDGMENTS

The material in this paper has been taken from various sources, some of which are given in footnote references. Some of the data were assembled by associate engineer C. W. Owings, Pittsburgh Experiment Station, Bureau of Mines.

ACCIDENT OCCURRENCE IN MINING

During the 5-year period 1906-10, inclusive, there were 84 major disasters (those in which 5 or more lives were lost) in United States coal mines. The total number of fatalities from coal-mine gas and dust explosions, major and minor, for the 5 years aggregated 2,388 or 477.6 per year. The shocking loss of life in the frequent coal-mine disasters so roused the country that the Federal Government was urged to act. This resulted in the establishment of the United States Bureau of Mines in 1910. The Bureau pioneered in research into causes and methods of accident prevention in the mining and allied industries; this and other activities of the Bureau of Mines in cooperation with State mining departments, mine operators, and others have been so effective that in 1933 there was only 1 major explosion in the coal mines of the United States and in 1934 only 2. During the 24 years existence of the Bureau of Mines there has apparently been a saving of about 7,300 lives from gas and dust explosions alone, or an average of more than 300 per year; that is, this number of lives would have been lost in mine disasters alone if the fatality rate from explosions that existed before the Bureau was established had been permitted to continue. During the past 6 or 7 years, rock-dusting, one of numerous measures recommended by the Bureau of Mines to check or prevent mine explosions, unquestionably has been instrumental in saving at least 200 lives annually and also preventing property damage amounting to several million dollars a year.

During the 5-year period 1906-10, inclusive, 13,288 persons were killed in the coal mines of the United States from all causes (including explosions), an average of 2,658 per year, and the fatality rate for this 5-year period was 5.89 persons killed per million tons of coal produced. In 1931 this figure was 3.31, in 1932 it was 3.36, and in 1933 it was 2.78; preliminary figures for 1934 indicate that the fatality rate was 2.77, with the probability that the 1934 figure will ultimately be about 2.85, or next to the lowest rate in the history of coal mining in this country, the rate of 2.78 in 1933 being the lowest or best rate so far recorded.

If the 5.89 fatality rate for the 5-year period 1906-10, inclusive, had continued to the first of January 1935, the lives lost would have been 25,500 more than the number re-

corded. Therefore, during the 24 years an average annual saving of life of nearly 1,100 persons is indicated. Similar figures are not available on prevention of nonfatal accidents, but it is estimated that there are about 50 nonfatal accidents to 1 fatality; therefore, at least 50,000 nonfatal accidents per year have also been prevented during the past 24 years in American coal mines alone, the total number for the 24 years aggregating the enormous sum of more than 1,200,000.

Downward Trend in Occurrence of Accidents in Mining.- The years 1930 to 1934, inclusive, have been decidedly encouraging to the proponents of health and safety in the mining and allied industries, notwithstanding the numerous vicissitudes that have been thrust upon not only health and safety workers but also upon all other persons engaged in these industries as well as upon the public at large. For the first time since health and safety have been actively fostered in the mines of the United States, those engaged in the work have been able to see not only trends toward better things but actually to find those trends substantiated by undeniable facts and figures showing the utter fallacy of the more or less universally held belief that mining is so inherently unsafe that efforts to operate mines safely are futile.

Table 1, taken from data in Bureau of Mines publications, gives illuminating information on the occurrence of fatal and nonfatal accidents in metal mines and quarries and on fatalities in coal mines.

TABLE 1.- Accident rates in metal mines, quarries, and coal mines in the United States, 1911-33 inclusive

Period	Metal mines, killed and injured per thousand 300-day workers (calculated)	Quarries, killed and injured per thousand 300-day workers (calculated)	Coal mines, killed per million tons of coal produced
1911-15	202.38	91.58	4.76
1916-20	245.04	162.39	3.86
Average 1911-20, Incl.	224.36	123.84	4.27
1921-25, Incl.	276.27	175.22	3.96
1926-30, Incl.	213.22	140.77	3.75
1926	248.48	162.15	3.83
1927	224.64	164.55	3.73
1928	208.11	131.41	3.78
1929	203.14	129.79	3.59
1930	170.78	109.76	3.84
1931	142.09	106.04	3.31
1932	138.46	97.33	3.36
1933	155.13	97.59	2.78
1934			[1]2.77

[1]Tentative and likely to be raised to about 2.85.

In this table the fatal plus nonfatal accident rates per thousand 300-day workers in metal mines and quarries are given by various periods from 1911 to 1933, inclusive; as similar figures are not at hand for coal mines (nonfatal accident data being unavailable, except since 1930) fatality rates per million tons of coal produced are given since they are the most definite data procurable on accidents in coal mining.

It will be noted that the fatal plus nonfatal accident rate per thousand 300-day workers in metal mines varied relatively little in the 5-year periods from 1911 to 1930, the rate

for the 5-year period 1926-30, inclusive, being somewhat higher than for the 5-year period 1911-15, inclusive. A study of the lower part of the table, giving the rates annually from 1926 to 1933, inclusive, indicates that the first real break in the metal-mining rate came in 1930 when for the first time it fell well below 200. After the break the improvement continued, the rate for 1931 being lower than that for 1930 and the rate for 1932 being slightly lower than that for 1931. The 1934 rate is not yet available.

In quarrying the break from a high accident rate to a definitely lower one came in 1930, and since then every succeeding year has shown a slightly lower rate than its predecessor, indicating that the industry has accident-prevention work well in hand, although the rate for 1933 was slightly higher than that for 1932.

In coal mines the fatality rate per million tons of coal produced remained obstinately high after the considerable lowering of the rate from 4.76 for the 5-year period 1911-15, inclusive, to the much more favorable rate of 3.86 for the succeeding 5-year period 1916-20, inclusive. The rate hovered around or was slightly under 3.85 until 1931 when the lowest rate known until that year (3.31) was achieved. The 1932 rate of 3.36 failed to equal the excellent record of 1931 but was the next lowest rate so far; the rate for 1933 was 2.78, or by all odds the lowest or best rate in the history of coal mining in the United States. Preliminary figures for 1934 give a rate of 2.77, but when final data are assembled this is likely to be raised to about 2.85, which is far lower than in any other year in the history of coal mining except 1933.

The table indicates that accident rates in metal mining began to be lowered definitely in 1930 and that additional progress was made in 1931 and 1932, although there was a slight recession in 1933, and although final figures are not available for 1934 (and won't be for several months) the rate for 1934 probably will not be as favorable as that for 1932. In fact, 1932 seems likely to hold the all-time safety record in metal mining in the United States, at least until the metal mines are again on a normal, steady producing basis; however, so many metal mines, especially those producing iron ore, have been able to operate almost without accidents that there is ample reason to believe that accident rates will again drop and probably drop fast when normalcy is reached in metal mining.

Table 1 shows that the definite downward trend in occurrence of quarry accidents began as far back as 1928 and that, as in other branches of mining, safety in quarrying suffered a slight set-back in 1933. However, the exceptionally fine accident performances of a number of quarries in the United States, notably those operated by cement companies, many of which have operated several years without a lost-time accident, indicate that quarry accident rates will probably sustain a definite fall extending over several years.

Coal-mining data in table 1 are restricted to fatalities on a tonnage basis, as these are the fullest and most reliable data available; the Bureau did not attempt to secure information on nonfatal coal-mine accidents prior to 1930. The table shows that definite progress in reducing the coal-mine fatality rate was lacking until 1931 and that in 1932, while the safety record was relatively good, it was somewhat poorer than that in 1931. However, in 1933, notwithstanding numerous influences which might be expected to increase rather than decrease the coal-mine fatality rate, the rate was actually by far the best or lowest in the history of coal mining in the United States; and while the rate in 1934 will probably ultimately be slightly higher than that in 1933, there is no question that it will be much lower than that of any other year except 1933.

It is thus seen that the definite downward trend in accident occurrence in mining started in 1930 or 1931. The reasons for optimism as to the future of accident occurrence in the mining and allied industries, notwithstanding the fact that the record for 1934 was undoubtedly poorer than that for 1933 or 1932, will be given later.

ACCIDENT COSTS

Obviously, all right-minded people should look upon safety, whether in mining or in any other walk of life, primarily from the humanitarian standpoint, as the prevention of loss of life and limb with its attendant suffering is a goal well worth almost any expendable effort. Unfortunately, however, human nature is so constituted that constant and universal application of high-minded principles to the prosaic features of industrial work is not and probably never will be obtainable. It is now evident to those most experienced in accident-prevention work that safety is likely to be achieved and "safety dividends" declared only when the officials in charge of mining or of other types of industrial projects actively support and encourage safety programs, and generally, although not invariably, the attitude of mining company executives can be interpreted in only one manner - safety expenditures must show a dollars-and-cents return on the investment. Although this is rather cold-blooded, perhaps it is logical, as industry to continue in existence under our present economic system must return a profit; hence, if safety is to be given any appreciable attention, it must also show a profit. A superintendent of a coal mine, in which accidents from falls of roof and coal were occurring with undue regularity, was informed by a trained safety engineer that unquestionably the accidents could be reduced greatly if more timbers were used; the reply was that additional timber would cost extra, therefore this accident-prevention plan was given scant consideration even though probably not only accident occurrence but also accident cost would have been reduced if the plan or a good modification of it had been adopted. A similar viewpoint is held by many superintendents, general superintendents, general managers, vice presidents, and presidents of mining companies, especially when these officials reside a considerable distance from the mine. Safety directors and safety workers in immediate contact with the mine usually consider saving in human life and suffering sufficient justification for spending money on safety, even if the company should receive no immediate dollars-and-cents return for such expenditures. To the surprise of most safety workers, a rigid accounting frequently reveals that so-called philanthropic expenditures for health and safety in mining have also paid large dividends in money.

Comparison of Accident Costs.- The figures published by the compensation commissions of the various States do not conform to any set type or standard, and it is practically impossible to correlate the various compensation costs. In some States the cost includes hospital and medical expense, while in others only the compensation outlay is given, and compensation for any given type of injury varies from State to State. The cost of compensation alone is given for seven States[3] in table 1. Arizona has one of the most drastic compensation laws in the United States, and while this is reflected in high costs in individual cases the progressive mining companies have been able to overcome the supposed handicap by intensive safety work, and their compensation costs per $100 of pay roll have been held definitely low. The cost of temporary disabilities in mining ranges from $15 in New York to $108 for bituminous mines in Pennsylvania. Permanent partial disabilities range in cost from $506 for mining in Washington (in 1930) to $3,686 for disabilities of more than 18 months in Arizona. Permanent total disabilities have the highest average cost, ranging from $6,526

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3 Ash, S. H., Accident Experience and Cost of Accidents in Washington Metal Mines and Quarries: Tech. Paper 514, Bureau of Mines, 1932, 35 pp.

New York Department of Labor, Cost of Compensated Cases: Special Bull. 178.

Ott, Lee, Nineteenth Annual Report of State Compensation Commissioner, West Virginia, for Year Ending June 30, 1932.

Herbert, C. A., A Review of Coal-mine Fatalities in Indiana During the Fiscal Year October 1, 1931 to September 30, 1932: Inf. Circ. 6746, Bureau of Mines, 1933, 16 pp.

Annual Report of Coal Section of Pennsylvania Compensation Rating and Inspection Bureau (mimeographed).

Fene, W. J., Accident Experience and Cost in Pennsylvania Anthracite and Bituminous Mines, 1926-30: Inf. Circ. 6618, Bureau of Mines, 1932, 29 pp.

Confidential unpublished data.

for bituminous mines in Pennsylvania to $15,484 for mining in Arizona; one California total disability finally resulted in a fatality 15 years later, and the hospitalization costs alone (including services of doctors, nurses, etc.) aggregated more than $43,000. The cost of fatalities ranges from $3,193 in West Virginia to $6,900 (for quarrying) in New York.

TABLE 2.- Compensation cost of accidents in seven States

State	Period	Average cost for each injury in dollars				
		Temporary disability	Permanent partial disability	Permanent total disability	Death	Average compensable disability
Arizona:						
Mining..........	1926 - 29	$77	[1]$642 [2]$3,686	$15,484	$6,521	$372
Indiana:						
Coal mining.......	1930	....	....	....	....	304
Do.	1931	....	....	....	....	334
New York:						
Mining..........	1930	15	633	....	6,603	415
Quarrying........	1930	18	999	....	6,900	649
All industrial.	1930	....	....	....	....	321
Pennsylvania:						
Bituminous........	1927 - 31	108	2,429	6,526	3,786	312
Anthracite..........	1927 - 31	107	2,084	6,829	4,572	387
Tennessee:						
13 coal mines....	1926 - 31	....	....	....	....	250
West Virginia:						
Industrial.........	1913 - 32	....	945	6,891	3,193	94
Washington:						
Mining..........	1924 - 30	38	830	8,624	5,348	244
Do.	1930	47	506	9,334	6,664	376

[1]Disability of 18 months or less.
[2]Disability of more than 18 months.
NOTE.- The data for this table were taken from various sources. (See footnote 3.)

The average cost of compensable injuries ranges from $94 for coal mining in West Virginia to $649 for quarrying in New York. The average cost of industrial injuries in New York in 1930 was $321, which agrees closely with an average estimate of $300 frequently made for compensable nonfatal industrial accidents in general. The average cost of nonfatal coal-mine accidents in Pennsylvania from 1916 to 1930 was $165. Numerous fatalities occur in mining in which the victim has no dependents, and the only direct cost, at least in some States, is that of a funeral; the cost of funerals in Pennsylvania coal mines averaged $103 from 1916 to 1930, and in West Virginia the funeral cost has been fixed at $150. It is believed that $100 is a conservative average for the cost of nonfatal accidents in mining in the United States, inasmuch as many nondisabling injuries in mining entail an expense of $10 or less.

The cost of nonfatal lost-time accidents has been placed at $300 for a year's experience of 30 petroleum companies with about 55,000 employees, and it was also stated that the cost of nonfatal lost-time accidents in the petroleum industry amounts to about $12 per year for every employee in the industry.

An insurance company gives the compensation and medical cost of nonfatal lost-time accidents in the construction industry as $378 for a recent 2-year period having a comparatively large number of cases. In his paper "Profits Through Reduction of Accidents" in the Mining Congress Journal of September 1932, J. T. Ryan places the cost of each nonfatal lost-time (compensable) accident at $168, which represents the experience of the Pennsylvania Department of Labor and Industry covering 1,169,820 cases since 1916. Recent 1934-35 accident experience on a large tunneling project in the western part of the United States gives the average cost of nonfatal lost-time injuries as $328; this report also stated that the man who sustained a lost-time injury received on an average $173 in compensation and sacrificed $608 in wages. In another part of the United States a large coal-mining company gave figures indicating that for a certain period employees were paid $1,217 as compensation for injuries sustained, and during this period of disability the lost wages aggregated slightly over $3,200.

In a study of a considerable number of no-lost-time injuries in 1934, a large tunnel-driving project found that for every such injury reported the first-aid and medical attention cost the employer $9. In a similar study of several thousand no-lost-time injuries a few years ago, a company mining coal, iron ore, and limestone and smelting and fabricating iron and steel found the average cost of these injuries to the operating company to be $4, which was approximately the daily wage at that time.

Maximum Costs of Fatalities.- The maximum compensation benefits that may be obtained under the various State compensation laws[4] are tabulated in table 3. Where the law specifies death or remarriage, a life of 20 years has been used. Where the workman leaves dependents compensation for death ranges from $3,000 in New Hampshire and South Dakota to as high as $50,000 (under some conditions) in Arizona. Death awards for a person who leaves no dependents range from $100 to $6,600; 5 States provide a payment to a special or rehabilitation fund, and 4 States provide payment to a second injury fund. Burial fees range from $75 to $200, the average being around $136.

Permanent total disabilities generally entail the greatest compensation cost, ranging from $3,000 to around or even over $50,000; temporary total disabilities range from $832 to $20,800, and these injuries also probably entail the maximum amount of grief and suffering in the long run. Partial disabilities have the lowest cost, ranging from $1,500 to $20,800. Medical and surgical costs are unlimited in a number of States, but estimated average costs range from $100 to $800.

The case of Jack Schaub, a California workman, attracted wide-spread interest and publicity; he was injured and became paralyzed from the hips down on December 13, 1917 and died on August 17, 1932. Hospital expenses were $24,943.94, nursing services $14,435.00, and doctor fees $3,848.46, or a total cost for the accident of $43,227.40. He lived for nearly 15 years after having sustained the injury and, of course, his sufferings during that time are not measurable in dollars and cents.

Medical and Hospital Cost.- Compensation is only part of the direct cost of accidents. Medical, hospital, and burial costs average from one fourth to one half as much as the compensation cost. During the 5-year period 1924 to 1928, inclusive, the compensation cost in California for 3,182 accidents, including 96 fatal accidents, was given as $1,054,580; medical aid was $505,142, or approximately 48 percent of the compensation cost and 32 percent of the total direct cost. Compensation costs for a group of mines in Arizona, during the 4 years ended December 31, 1930, were $464,336.17, and medical aid amounted to $86,227.50, or about 18 1/2 percent of the compensation and nearly 16 percent of the total cost. In 13 coal

4 U.S. Bureau of Labor Statistics, Department of Labor, Workmen's Compensation Legislation of the United States and Canada: July 1926.

TABLE 3.- Maximum compensation benefits, by States

State	Death			Total disability		Partial	Medical
	Dependents	No dependents	Burial	Permanent	Temporary	disability	aid
Alabama	$5,000	$100	$100	$5,000	[1]$4,500	[1]$4,500	$100
Arizona	[2]30,000	[3]1,000	150	[4]50,000	[5]6,500	[6]6,500	[7]300
California	5,000	150	150	[8]5,000	5,000	5,000	[7]300
Colorado	3,750	125	125	[4]12,480	3,750	3,120	300
Georgia	5,000	100	100	5,000	5,000	[1]3,600	100
Idaho	[9]4,800	[3]1,200	200	[9]6,400	[9]6,400	[10]2,400	[7]300
Illinois	4,550	[11]450	150	[12]7,904	3,750	[12]7,904	[7]300
Indiana	5,000	100	100	5,000	5,000	[1]9,000	[7]300
Iowa	[1]4,500	250	150	[9]6,000	[1]4,500	[7]4,500	100
Kansas	4,000	150	150	[12]7,488	[12]7,488	[12]7,488	100
Kentucky	4,000	175	75	6,000	6,000	[1]6,000	200
Maine	4,000	200	200	6,000	6,000	5,400	100
Maryland	5,000	125	125	5,000	3,750	3,750	500
Massachusetts	10,400	[11]250	100	4,500	4,500	4,500	[7]200
Michigan	[1]5,400	200	200	9,000	9,000	[13]9,000	[7]200
Minnesota	7,500	[11]350	150	10,000	10,000	[1]6,000	[7]200
Missouri	[1]6,250	250	150	[1]6,000	[9]8,000	[14]2,000	250
Montana	[9]6,000	125	150	[15]7,500	[1]6,000	[10]2,250	500
Nebraska	[10]5,250	150	150	[1]4,500	[1]4,500	[1]4,500	[7]200
Nevada	[2]19,200	150	150	[4]8,640	7,200	[17]2,400	[7]500
New Hampshire	3,000	100	100	[1]4,500	[1]4,500	[1]4,500	[7]100
New Jersey	[1]6,000	250	150	[9]8,000	[4]6,000	[15]10,000	100
New Mexico	[1]9,000	225	75	[18]6,240	[18]6,240	[7]18,750	150
New York	[2]36,000	[3]1,200	200	[4]26,000	5,000	4,000	[7]300
North Dakota	[2]15,000	150	150	[2]15,000	[7]20,800	[7]20,800	[7]300
Ohio	6,500	150	150	[4]5,850	3,750	3,750	200
Oklahoma	....	....	....	[15]9,000	[1]5,400	3,000	100
Oregon	[2]31,200	100	100	[4]36,400	[7]18,200	2,400	250
Pennsylvania	[1]7,200	150	100	6,500	6,500	[1]4,500	100
Rhode Island	[1]4,200	200	200	5,000	5,000	[1]3,000	200
South Dakota	3,000	150	150	3,000	[19]4,650	[19]4,650	200
Tennessee	[9]6,400	100	100	5,000	[1]4,800	[1]4,800	100
Texas	[20]7,200	100	100	[21]8,020	[21]8,020	[1]6,000	[7]200
Utah	5,000	[11]1,150	100	[4]16,650	5,000	5,000	500
Vermont	3,500	100	100	4,000	4,000	[22]2,600	200
Virginia	4,500	150	100	4,500	4,500	[1]3,600	[7]200
Washington	[2]13,200	100	100	[4]9,600	[4]9,600	3,000	[7]200
West Virginia	[2]7,200	150	150	[4]16,640	[23]832	[4]16,640	800
Wisconsin	6,000	[3]6,600	200	[24]19,500	[25]6,000	[7]19,500	[7]200
Wyoming	3,600	150	150	8,000	8,000	1,500	300

(See page 9 for footnotes)

FOOTNOTES FOR TABLE 3

[1]300 weeks.
[2]Death or remarriage, estimated 20 years.
[3]Payment to rehabilitation or special fund.
[4]Life, estimated 20 years.
[5]100 months.
[6]60 months.
[7]Estimated.
[8]240 weeks.
[9]400 weeks.
[10]150 weeks.
[11]Payment to second injury fund.
[12]8 years.
[13]500 weeks.
[14]100 weeks.
[15]500 weeks.
[16]350 weeks.
[17]60 weeks.
[18]520 weeks.
[19]6 years.
[20]360 weeks.
[21]401 weeks.
[22]260 weeks.
[23]52 weeks.
[24]1,000 weeks.
[25]4 years.

NOTE.- Oklahoma makes no provision for deaths.

This table was taken from data in U.S. Bureau of Labor Statistics, Bull. 423.

mines in Tennessee compensation cost $146,087 and medical aid $46,817, or the medical cost was about 32 percent of the compensation cost and more than 24 percent of the total cost. From 1925 to 1929, inclusive, medical aid in Pennsylvania[5] cost 65 1/2 percent of the compensation for temporary disabling injuries and about 7 1/2 percent of the compensation for deaths in bituminous mines.

One coal-mining company reduced its accident occurrence materially, and the direct cost of accidents dropped from about 7.5 cents per ton to 1.5 cents per ton; in producing about 1,030,000 tons of coal with a direct cost of accidents of about 1.5 cents per ton, this mine had $3,955 charged to hospitalization and $11,830 to compensation, hence the hospitalization (doctor plus hospital charge) was about 33 percent of the cost of compensation and about 25 percent of the total direct cost of accidents.

In a paper in the Mining Congress Journal of September 1932, J. T. Ryan sets the "medical attention and hospitalization" cost of producing coal at 0.5 cent per ton besides the compensation cost of 5 cents per ton.

The cost of infections is more serious than is usually believed. In a bulletin issued to its employees in 1933, the Cleveland Cliffs Iron Co. had the following interesting information:

> Infections are Often Serious
>
> Based on insurance and compensation figures the following estimates have been made:
>
> 1. About 250,000 cases of infected wounds develop every year.
> 2. Insurance companies pay from 40 to 60 percent of their compensation for infected wounds.
> 3. The lost time for a case of infection averages 18 weeks longer in disability than of a noninfected case.
> 4. There is a total annually of about $104,227,500 from infected wounds in industry; the total loss of time involved is 4,458,333 weeks, or the equal of 85,737 years.
> 5. About 90 percent of all industrial injuries occur to the hands and fingers.
>
> It is probable that most of such cases are only scratches or small cuts to start with. First aid or prompt treatment by the doctor are by no means a needless bother; the chances are all the other way.

COST OF INJURIES BY PARTS OF BODY AFFECTED

The cost of injuries varies in general according to the part of the body affected. The cost fluctuation is due largely to the ease or difficulty of healing the wound which governs the medical aid and hospital costs. If the injury causes the loss of a part of the body, compensation laws usually govern the compensation paid. The costs of personal injuries for a coal-mining company[6] which gives considerable attention to safety are segregated in table 4 according to the type of injury.

5 Information submitted by letter to author. Sources given in footnote 3.

6 Name of company withheld by request.

TABLE 4.- Cost of personal injuries of a coal company for 4 years

Nature of injury	Number of injuries	Injury payments	Average cost per injury
Head and face......	109	$1,766.29	$16.20
Eye........	124	1,975.84	15.93
Arm........	64	479.81	7.50
Leg..............	88	5,514.10	62.66
Hand and finger..	232	6,119.53	26.38
Foot and toe.......	109	2,971.91	27.27
Body......................	93	1,734.13	18.65
Fatal.....................	6	20,775.00	3,462.50
Total...........	825	41,336.61	....

The 4-year cost to this coal company of injuries to its employees ranges from $62.66 for leg injuries to $7.50 for arm injuries; the cost of fatal accidents averaged $3,462.50 each. The average cost of all accidents, including fatalities, was $50.10, and nonfatal injuries averaged $25.11; evidently the most costly parts of the body injured in this mine are the legs, hands, fingers, feet, and toes.

The coal-mine section of the Pennsylvania Compensation Rating and Inspection Bureau, in a comprehensive study and analysis of coal-mine accident costs over a certain period, shows that the average cost of injuries in the anthracite mines was $415, of which amount compensation comprised $337 and medical aid $78; and the average cost of injuries in bituminous mines was $321, the compensation costing $257 and medical aid $64.

The compensation and medical-aid costs of major permanent disabilities, minor permanent disabilities, temporary disabilities, and noncompensable injuries are listed in table 5, by parts of body affected, for coal mines of Pennsylvania from 1925-29, inclusive.

The cost of major permanent injuries for the period 1925-29, inclusive, averaged $2,351 in anthracite mines and $2,378 in bituminous mines; the loss of an arm cost $3,622 and $3,800 in anthracite and bituminous mines, respectively; the loss of a hand cost $2,724 and $2,754, the loss of a leg $3,685 and $3,485, the loss of a foot $2,331 and $2,525, and the loss of an eye $2,137 and $2,892 for anthracite and bituminous mines, respectively. The medical cost for major permanent disabilities averaged $196 for anthracite mines and $232 for bituminous mines; for minor permanent injuries the medical cost was $72 and $80, respectively. The cost of major permanent disabilities in Pennsylvania in 1925-29, inclusive, was slightly more than half as much as that of fatalities, the total fatality cost being $4,140,969 and the major permanent disabilities costing $2,719,951. Temporary disabilities cost practically the same as fatalities - $4,142,161. The total cost of nonfatal injuries was $8,859,093, or more than twice the cost of fatal injuries. Loss of eyes constituted the greatest loss, averaging $468,639; loss of feet, totaling $265,952, ranked second; loss of legs, $255,588, was the third largest cost; loss of hands, costing $205,381, and loss of arms, totaling $124,328, were fourth and fifth, respectively, in the cost of major permanent disabilities.

Accidents in 10 mines in the Southern Appalachian coal field[7] cost $130,000 in 5 years, including hospitalization, X-rays, and lawsuits. The average cost was 2.5 cents per ton of coal mined. The cost of 35 permanent partial disabilities, entailing a loss of 16,583 days, was $33,079.66; 628 temporary total disabilities, resulting in 21,390 days lost time, cost $25,343.98, or an average of $40.36 each.

7 Source of information confidential.

TABLE 5.- Loss analysis, by parts of body injured, in Pennsylvania coal mines 1925 to 1929, converted to the 1928 level[1]

Anthracite Mines

Severity of injury	Average cost	Average compensation	Average medical cost
Major permanent......	$2,351	$2,155	$196
Loss of arm..........	3,622	3,418	204
Loss of hand........	2,724	2,536	189
Loss of leg..........	3,685	3,375	310
Loss of foot.......	2,331	2,134	198
Loss of eye..........	2,137	2,012	125
Disfigurement......	609	520	89
Other permanent..	3,158	2,895	263
Indeterminate......	1,945	1,700	245
Minor permanent......	477	405	72
Temporary................	115	71	44

Bituminous Mines

Severity of injury	Average cost	Average compensation	Average medical cost
Major permanent......	2,378	2,146	232
Loss of arm..........	3,800	3,522	278
Loss of hand........	2,754	2,544	210
Loss of leg..........	3,485	3,186	298
Loss of foot........	2,525	2,245	281
Loss of eye..........	2,033	1,892	142
Disfigurement......	2,892	2,591	301
Other permanent..	1,887	1,667	220
Minor permanent......	509	420	80
Temporary................	115	74	40

[1]From the 1929 report of the coal-mine section of the Pennsylvania Compensation Rating Bureau.

The parts of the body affected, and the average cost of the accidents, in these 10 mines were as follows: 47 hand injuries, $25.56; 164 injured fingers, $37.84; 24 injured arms, $26.52; 37 injured eyes, $19.33; 39 injured heads, $33.34; 29 strained backs, $52.58, 74 injured legs, $82.87; 64 injured feet, exclusive of injured toes, $33.86; 29 injured ankles, $41.78; 40 injured toes, $28.44; 10 hernias, $85.71; and 73 other body injuries, $37.71. These figures are not confined to loss of a member or members as were the Pennsylvania costs, and the relative figures are therefore different. In the opinion of the man in charge of the compensation, the injuries were the direct result of carelessness except in one or two instances.

The December 1934 Monthly News Letter of the public utilities section of the National Safety Council contained the following interesting item under the caption "What Price Fractures:"

> Fractures are costly both to the employee and the employer. They are not only costly, but they cause excruciating and unnecessary pain.
>
> From a recent analysis covering 162 fracture cases which occurred during 1933, as compiled by a large public utility, the average loss of time for a frac-

ture was 172 days. The following tend to bring out the 'highspots' of the analysis:

	Days
Average disability for a fracture of any part of the head..	2,269
Average disability for a fracture of any part of the body exclusive of the head, upper and lower extremities..........	311
Average disability for a fracture of the leg..........................	136
Average disability for a fracture of the arm..........................	57
Average disability for a fracture of the foot..........................	34
Average disability for a fracture of the toe..........................	14
Average disability for a fracture of the finger......................	3

The average medical costs for the various types of fractures were:

Head	-	$150.00
Body	-	334.01
Leg	-	221.63
Arm	-	230.78
Foot	-	108.94
Toe	-	39.35
Finger	-	45.48

While the preceding data refer only to accidents of a certain type in connection with a "large public utility" rather than a mining organization, they give information of value as to days lost in connection with certain types of accidents to various parts of the body and the average medical cost of treating these accidents.

The mean minimum compensation payment to injured persons in mining States of the United States[8] is about $6.00 a week, and the mean maximum is about $15.00 per week. The scale of time losses for weighting industrial disabilities used by the Bureau of Mines classes a fatality, permanent total disability, and loss of sight in both eyes as total disabilities and assigns 6,000 days as the time lost. On this basis the minimum cost of the loss of both eyes would average $5,143, and the maximum cost would average $12,857. Loss of arm above the elbow or loss of leg above the knee is classed as 75-percent disability, hence the minimum cost would be $3,857 and the maximum cost $9,643. The loss of an arm at or below the elbow would cost $3,086 to $7,714; loss of a hand, leg below the knee, and hearing of both ears constitute 50 percent disability and would cost $2,572 to $6,429. The loss of the great toe would cost $257 to $643, and the loss of any other toe carries no specified compensation. The loss of a finger costs the same as a great toe, and the loss of a thumb costs twice this amount. Thus it is seen that the loss of a member of the body, or permanent impairment of it, is likely to be an expensive accident.

The United States Bureau of Mines analyzed 8,017 temporary injuries causing an aggregate loss of 114,665 days lost time, or an average of 14 days per injury. In this somewhat limited study it was found that the mean minimum cost of temporary disabilities throughout the United States averaged $12, and the maximum averaged $30 for compensation alone. The average head and face injury caused a loss of 9 days, resulting in a cost of $7.72 to $19.30. Eye injuries averaged $6.85 for one eye and $10.30 for two eyes as a minimum and $13.72 and $25.78 as a maximum. The average lost time from injuries to the upper extremities was 14 days, entailing an average cost of $12 to $30. The cost ranged from $8.56 to $21.41 for a wrist injury and from $48 to $120 for an injured humerus. Finger and thumb injuries caused

8 See footnote 4.

an average loss of 14 days, the lowest average being 12 days for the ring finger and the highest being 15 days for a little finger, the minimum cost averaging $10.29 to $12.85 and the maximum cost $25.70 to $32.15. The average injury to the trunk caused a loss of 16 days and cost $13.70 to $34.25. Lower extremities, when injured, averaged 18 days lost time at a cost of $15.43 to $38.60. Knee injuries cost from $12.85 to $32.15, and injuries to the kneecap averaged $32.60 to $83.50. Toe injuries, averaging 13 days lost time, cost from $11.15 to $27.85. Medical cost in the above cases was not considered; however, for minor injuries the medical cost is likely to be practically equivalent to the compensation cost.

COST OF NONFATAL ACCIDENTS BY CAUSES

The cost and analysis of 95 nonfatal accidents in a coal mine,[9] covering a 2-year period, are given in table 6. This analysis does not include all accidents, but it shows a definite trend in accident costs for nonfatal injuries. A comparison of the number of man-hours lost and the cost of settlement indicates that in this mine nonfatal injuries cost nearly 91 cents per hour of lost time.

TABLE 6.- A critical analysis of accidents in a coal mine over approximately a 2-year period

Number of cases	Cause	Number of man-hours lost	Settlement expense
1	Employee not instructed at all	16	$33.42
5	Instructions not enforced	152	370.82
2	Instructions incomplete	192	60.61
7	Employee not skillful	208	247.19
3	Employee ignorant	409	211.82
6	Employee used poor judgment	234	344.72
10	Disobedience of rules	692	1,590.95
12	Interference by others	1,399 1/2	1,124.07
1	Attention distracted	162	214.70
11	Inattention	2,004	2,134.42
7	Taking chances	1,056	695.71
1	Short cuts	128	38.42
3	Haste	114	116.95
3	Employee sluggish or fatigued mentally	272	72.45
1	Employee excited or angry	128	26.02
4	Employee physically defective	341	103.29
1	Employee fatigued physically	34	23.56
1	Danger points inadequately guarded	1,408	765.90
1	Untidy or otherwise dangerous passages or work spaces	120	109.28
1	Clearances insufficient for safe work	24	12.84
1	Improper tools used	16	45.12
6	Method of doing work improperly planned	616	810.00
1	Unsafe lay-out of plant	176	32.98
6	Proper personal safety equipment not available	256	234.06
	Total	10,157 1/2	9,189.53

9 Name of company withheld by request.

DIRECT COST OF ACCIDENTS

Direct costs are ascertained fairly readily insofar as the employer is concerned; they comprise the compensation paid to the injured man, the medical and surgical fees, and the hospital fees and expenses and usually are tangible deductions from the funds of the employer. Wages lost by the injured employee or other dollars-and-cents costs to him do not affect directly the operating cost of a mine or quarry and are not included in the usual acceptance of the "direct" cost of accidents in or to industry. However, the injured worker usually is given in compensation very much less money than he would have earned if he had continued at work uninjured, in addition to immeasurable losses in pain, misery, and other hardships, mental and physical, to him and possibly to many others connected with him as relatives, friends, or otherwise. Of course, the dollars-and-cents loss to the worker and his family in a fatality or a permanent total disability cannot be calculated.

Washington may be taken as representative of States in which direct costs of coal-mine accidents are high due to various factors and conditions. In 1927 compensation and medical costs averaged 11.0 cents per ton; in 1928, 7.9 cents per ton; and in 1929, 9.0 cents per ton. The 1913 to 1929 average was 8.05 cents per ton, according to S. H. Ash in Bureau of Mines Information Circular 6529; this circular shows that the cost per $100 of pay roll was $3.74 from 1913 to 1929, although in 1929 the cost was $4.63. The compensation and medical cost of accidents in Washington metal mines and quarries (Bureau of Mines Technical Paper 514) during the 7-year period 1924-30 averaged $3.36 per $100 of pay roll, ranging from $1.69 in 1924 to $5.87 in 1929.

Accident costs for medical aid and compensation in 8 metal-mining States, according to a report of a special California Senate committee which in 1931 investigated mining compensation-insurance rates, averaged for California $5.50 per $100 of pay roll, for Idaho $2.77 and for New Mexico, $2.33, the figures for these 3 States being based on the period 1924-28; for Colorado, $3.68, in 1923-27; for Montana, $5.28, in 1924-28; for New York, $6.46, and for Utah, $3.99, in 1923-27; and for Nevada, $3.05, in 1929-30. The average direct cost of compensation and medical aid for the above 8 States and Washington was $4.05 per $100 of pay roll.

Medical and compensation cost in Pennsylvania from 1926-30, inclusive,[10] was 3.19 cents per ton for coal insured by the State fund and 3.22 cents per ton for bituminous coal from all mines. This cost ranged from 2.62 cents per ton in 1927 to 3.44 cents per ton in 1928. The average cost for the bituminous mines of Pennsylvania for the 5-year period 1926-30 was 2.93 cents per ton; and for the anthracite mines of Pennsylvania the average cost was 5.43 cents per ton, ranging from 3.43 cents in 1926 to 7.26 cents per ton in 1930. The added direct accident cost of 3, 4, or more cents per ton of coal mined may be the difference between operating at a loss or profit, and it must be remembered that the direct cost is only a relatively small part of the total cost of accidents.

The direct cost of accidents in and around the coal mines of the United States probably averaged at least 4 or 5 cents a ton of coal mined with wages and contract rates as of 1931 and 1932 and about 5 1/2 to 6 cents in 1933 and 1934. A similar comparison cannot be made for metal and nonmetallic mines and tunnels, but the cost per $100 of pay roll in 1933 and 1934 may be estimated to range from a low of $3.40 to $4.00 to as high as $15.00 for metal mines and perhaps as high as $35.00 for tunneling.

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10 Fene, W. J., Acident Experience and Costs in Pennsylvania Anthracite and Bituminous Mines, 1926-30: Inf. Circ. 6618, Bureau of Mines, 1932, 29 pp.

INDIRECT COST OF ACCIDENTS

Until the past few years most mine officials have avoided rather carefully discussions or the compiling or giving of data on the dollars-and-cents costs of accidents, and this has been decidedly detrimental to progress in safety in mining. At present some mine managements fail to understand the direct loss caused by accidents, and relatively few of them study or realize what is meant by the indirect cost of accidents to the management or the enormous losses involved. Statistical studies have shown that when an accident occurs and afterward there are numerous losses to the employer in addition to the compensation and medical costs in connection with the injured man or men. At the time of and after an accident considerable time is lost by other workmen in assisting the injured workman, in stopping work to view the place where the accident occurred and to discuss the incident with fellow workmen, or in clearing away the wreckage to mine or plant due to the accident. In some mining localities all men stop work if a man is fatally injured; the production thus lost may have a decided effect on the profits. Many accidents occur in and around mines without injury to persons but with heavy loss to the company. An extreme example of a noninjury accident[11] shows how much one accident may cost. A workman, on coming out of a mine, stopped to warn the foreman that some bad roof on a haulage road was "working." The foreman said he did not have time to attend to it then but might at some other time. The roof fell and caused the closing of a section in which coal production was about 150 tons a day; this was in 1920, and the company was selling its coal for about $10.00 a ton, the profit being about $6.00 a ton. Failure of the foreman to try to prevent this accident cost the company at least $900.00, and it was only good luck that prevented one or more workmen from being caught by the fall. Other indirect costs are the expense of the supervisors in making an investigation of the accident, damage to equipment, cost of hiring new men to replace the injured employee, and many others, any one of which may be decidedly costly.

The cost of employing new men to take the place of those who have been injured may be heavy. A large coal-mining company, after making a thorough study of the cost of hiring a man, estimated that it cost at least $25 to hire and put to work the least skilled employee and as much as $2,000 or even $3,000 to employ a new foreman or superintendent.

The indirect cost to the employer of accidents in dollars and cents has been estimated to be at least four times the direct cost, hence the cost of compensation and hospitalization is thought to be only about one fifth of the total cost to the employer. On this basis the indirect cost of coal-mine accidents in Washington would amount to 32.20 cents per ton from 1913-29 and in Pennsylvania bituminous mines to 11.72 cents per ton from 1926-30. For anthracite mines the indirect cost would have been 21.72 cents per ton during the same period.

An excellent analysis of the factors likely to enter into the indirect cost of accidents is given in the October 1934 Monthly News Letter of the wood products section of the National Safety Council, as follows:

> These costs are conservatively estimated to be not less than FOUR times the amount paid in compensation, medical, and hospital expense. Moreover these items are NOT INSURABLE.
>
> 1-Time lost from production by employee as a result of injury.
>
> 2-Time lost from production by other employees who stop work (a) Out of curiosity, (b) to assist injured, (c) out of sympathy, and (d) because of nervous shock.
>
> 3-Temporary slowing down of production in department because (a) Employees gather in groups to talk about accident, and (b) thoughts of the acci-

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11 Source of information confidential.

dent continue to divert their attention from their work. (This may also lead to another accident, spoiled material, or damage to equipment.)

4-Time lost from production by foremen, supervisors, or other executives to (a) aid injured employee, (b) investigate cause of accident, (c) arrange for injured employee's production to be continued by some other employee, (d) select, train, or break in new employee to replace injured one, (e) prepare accident reports for employer, insurance carrier, and State, and (f) attend hearings before State Industrial Accident Commission.

5-Time of first-aid attendant and hospital department staff (when not paid by insurance).

6-Spoilage and waste of material caused by accidents.

7-Damage to machine, tools, building, or other property.

8-Losses due to interference of accidents with production, such as failure to fill orders on time, loss of bonuses, payments of forfeits, cancellation of orders, loss of customer goodwill, etc.

9-Loss of profit on productivity of employees affected by the accident and on machines temporarily idle.

10-Loss in putting injured employee back on pay roll and paying full wages when injured is not fully recovered and is unable to earn the wages paid.

11-Loss through inferior productive effort due to inability (where high accident rates prevail) to attract and hold high-grade workers. Inferior workers waste more and cause more accidents.

Probably the most convincing exposition of the far-reaching consequences of the indirect cost of accidents is found in a paper entitled "The Cost of Industrial Accidents to the State, the Employer, and the Man", by H. M. Heinrich, of the Travelers Insurance Co., read before the International Association of Industrial Accident Boards and Commissions in Wilmington, Del., on September 23, 1930. Mining people who have not read this excellent address should by all means do so.

One of the serious factors in the indirect or hidden cost of accidents is the expense to the employer for the noncompensable accidents, large numbers of which are likely to occur in any mine or mining plant. A few years ago a large-capacity steel company with coal, iron ore, limestone, and other mines, as well as blast-furnaces and fabricating plants, studied several thousand accidents in which the injured person lost no pay time and the company paid no compensation. The accidents included slight cuts on finger or hand, a sliver in a finger, etc., and the injured person continued with his day's work. It was determined that the average cost of every such accident to the company was $4.00, which happened to be the average daily wage at the time. The October 1934 Monthly News Letter of the Wood Products Section of the National Safety Council had the following analysis of the cost factors entering into accidents of this type:

> To 1 accident causing injury and loss of productive time of employee, there are, in industry, 29 accidents that result in slight injuries without loss of time (except for first aid) and 300 NO-INJURY ACCIDENTS.
>
> These 300 NO-INJURY ACCIDENTS cause:
>
> 1-Loss of time of workers, foremen, superintendents, plant engineers, and others in making repairs, getting things going again, doing a job over, etc.
>
> 2-Damage to machinery and equipment.
>
> 3-Waste of materials and supplies.
>
> 4-Interference with production schedules, delays, waiting for new machine part after break-down, etc., and increased hazards from rushing the work afterwards.

In the coal and metal mines of the United States scores of fires occur annually in which no life is lost and no workers are injured. Very few of these fires are controlled and extinguished successfully with an expenditure of less than $100, and some of them cost over $100,000. There also occur annually numerous falls of material, wrecks of haulage equipment, and similar accidents in all types of mines, as well as explosions of gas or dust in our coal mines, without injury or death to persons but with heavy damage to the mine or plant and resultant expense in restoring normal operating conditions; in some cases these no-inury accidents cost thousands of dollars.

When all of the phases which enter into the indirect cost of accidents (including those in which injury or death occurs as well as those devoid of personal injuries) are considered one is forced to believe that the indirect cost must be several times (and probably at least four times, as is usually given) the direct cost of accidents. Therefore, it behooves the mine management to try to its utmost to avoid the occurrence of all kinds of accidents in and around mines. While this may seem Utopian and impossible of fulfillment, the results now being obtained by many mining companies with well-directed safety effort give ample promise that the goal may be reached approximately if not absolutely.

TOTAL COST OF ACCIDENTS IN MINING

It appears that the direct cost of accidents in coal mining is at least 4 cents (and probably nearer 5 cents per ton of coal produced) and that their direct cost in metal and other types of mining is around or over $5.00 per $100.00 of pay roll. If the indirect cost is 4 times the direct cost, as is now thought to be approximately correct, then the total cost (direct plus indirect) of accidents in coal mining in the United States is around 20 cents or possibly 25 cents per ton, and the total cost of accidents in metal and nonmetallic mineral mining is around $25.00 per $100.00 of pay roll.

Probably 20 cents per ton is not 1 cent too high for the total cost of accidents in coal mining, and certainly 15 cents per ton is far too low. Twenty-five dollars per $100.00 of pay roll seems high for the total cost of accidents in metal and nonmetallic mineral mining, but $18.00 or $20.00 is conservatively low. These figures are 10 or more percent of the mine cost of production, therefore, at least 10 percent of the mine cost of producing our mineral products, coal, ore, or nonmetallic mineral products, is brought about through the occurrence of accidents.

INSURANCE COSTS

Insurance companies have found that the loss ratio for casualty insurance in mining exceeds the premiums, in some cases averaging as much as 1.22. For that reason many of the large insurance companies have withdrawn from taking risks in the mining industry, and generally where such insurance is granted the insurer must give other types of insurance to the insurance company so that the latter may try to "break even" on the compensation and attendant losses. The various States have practically been forced to offer insurance to mining companies, and apparently the rates are high. The mining premium rates per $100 of pay roll in 1930[12] were as follows: California, $10.54; Arizona, $7.79; Colorado, $5.03; Idaho, $4.15; New Mexico, $4.57; Nevada, $5.10; Utah, $6.00; and Washington, $3.36.

Safety effort and the use of safety equipment in mining operations are recognized in some States by allowing a credit for the adoption of safety measures and equipment as well as

12 Ash, S. H., Accident Experience and Cost of Accidents at Washington Metal Mines and Quarries: Tech. Paper 514, Bureau of Mines, 1932, 35 pp.

for past safety accomplishment. In others, no credit is allowed. Unquestionably this is unfair and places a premium on carelessness and incompetence in safety effort and performance; it also handicaps very seriously (and in many instances the handicap is so nearly intolerable that well-intentioned mining companies are forced out of business) the mining organization that tries to operate safely or that actually does operate safely. In many cases, the premium is so high that some companies that have given safety careful consideration have become self-insurers as an added means of securing SAFETY DIVIDENDS and have had the satisfaction of reaping these dividends in full measure.

A metal mine paying $3.10 compensation per $100 of pay roll came under the supervision of a mining man who had established very good safety records in his previous places of employment. He had the company "take over" its own compensation obligations, and instituted an accident-prevention campaign. In less than a year the rate was reduced to considerably less than $1.00 per $100 of pay roll. This seems miraculous, but this man had accomplished essentially the same feat in handling other mining operations, hence knew that "it could be done."

President C. W. Crane, of the St. Joseph Lead Co., read a paper on safety before the mining section of the National Safety Council in Cleveland, Ohio, on October 4, 1934; a paragraph from a discussion of Crane's paper in Coal Age of November 1934 reads as follows:

> Every company should keep a balance account of the cost of the safety department and of its accomplishment. The 6-year average of cost of compensation of the St. Joseph Lead Co., a self-insurer, is $1.66 per $100 of pay roll. The safety work costs 73 cents per $100 of pay roll, this covering the salaries and expenses of the safety department. The cost, therefore, has been $2.39. The company would have had to pay $4.66 had it purchased compensation, and the average cost of such compensation for the mines of the State was $8.66. Actual costs for compensation should be known to every foreman, and the direct saving from his individual efforts should be always in his mind.

REDUCING COSTS THROUGH SAFETY ACCOMPLISHMENT

Examples of the monetary savings possible through the adoption of a complete safety-organization plan and institution of a determined, well-thought-out safety campaign are easily found, and a few will be given. In 1925 one mine[13] with an average of 125 employees had 3 fatalities, 28 compensable disabling injuries, and 17 noncompensable disabling injuries, resulting in 18,986 days lost time; in 1926 it had 1 fatal, 1 permanent total, 1 permanent partial, 38 compensable, and 29 noncompensable disabling injuries, causing 14,991 days lost time; in 1927 it had 3 fatal accidents and 11 compensable and 15 noncompensable disabling injuries, causing a total loss of 18,705 days. In October 1927, through suggestions of a representative of the Safety Division of the United States Bureau of Mines, a safety-organization plan was instituted, and a vigorous safety campaign was put into and kept in effect. No deaths have occurred, so far as known, since January 1, 1928; moreover, no permanent disabilities are known to have occurred since that date. In 1928 there were 2 disabling accidents, causing 1,820 days lost time, of which 1 was compensable. In 1929, 4 compensable and 7 noncompensable disabling injuries resulted in 144 days lost time. During 1930, 5 compensable and 2 noncompensable disabling accidents caused 308 days lost time. On January 8, 1931 two miners received crushed fingers from a rock rolling and catching their fingers against the side of the car that they were pushing; from then to May 25, 1933 there were no disabling

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13 Name of company withheld by request.

accidents in the mine. A surface employee was injured on July 17, 1931, and no further disabling injuries occurred in the plant until March 28, 1933.

The company was insured through a casualty insurance company, but after inaugurating the safety campaign the company became self-insuring. The cost of accidents in 1927 was $40,-181.63. After the safety program was put into effect, the cost of accidents was reduced to $5,859.32 in 1928, $2,769.29 in 1929, $3,720.00 in 1930, $934.29 in 1931, $86.92 in 1932, and $601.16 in 1933. If the 1927 rate had been in effect from 1928 to 1933, accidents would have cost $241,089.78, hence the savings in 6 years may be estimated at $227,118.80. This company undeniably made a substantial saving by assuming full responsibility for accident occurrence and then trying to eliminate accident occurrence.

Safety is or at least should be an operating problem, and executives who have adopted it as such and have given intelligent, well-directed effort to the work have returned safety dividends to their companies. Safety workers thoroughly believe that supervision and discipline are the keynotes to accident reduction or elimination, although they recognize that under some conditions both may be handicapped through influences beyond control of those in charge of industrial operations. A large coal-mining company[14] changed from hand-loading to mechanical-loading methods, and although such changes have resulted frequently in higher accident costs the increased supervision and the close attention given to safety resulted in a lowering of the injuries from 8.9 per thousand man-shifts during 2 1/3 years with hand loading to 5.0 per thousand man-shifts during 1 2/3 years with mechanical loading. The accident costs (direct costs only) decreased from 5.5 cents per ton with hand-loading to 3.2 cents per ton with mechanical loading; the saving amounted to $29,203.33, or at the rate of $17,522 a year. It is doubtful if any other department of the company, even by the closest figuring, could have effected a proportionate saving, especially as the "dividend" was obtained with little or no additional outlay of money, supervision being the governing factor.

In a statement in 1934, James Berry of the Ohio Department of Mines is quoted as follows:

> Prior to 1933 mine accidents in this southern section (of Ohio) cost 5.6 cents per ton for each ton of coal mined there. Following the organization of safety department in that locality, accidents now cost approximately 1.7 cents per ton for each ton taken out of the ground.

The above statement, taken from the Hanna Coal News of September 1934, indicates that these Ohio coal mines, by going systematically into safety work, cut the direct cost from 5.6 cents to 1.7 cents, or 3.9 cents per ton. If the direct cost of accidents is only one fifth of the total cost, this safety work has reduced the cost of coal production by 5 times 3.9 cents, or 19.5 cents per ton, certainly a worthwhile saving.

A coal-mining company operating several small mines paid in compensation nearly $18,000 in 1929 and over $22,000 in 1930. In 1930 Bureau of Mines 100-percent first-aid training was given, and a Bureau of Mines engineer made safety inspections and reports on the mines; this plus other safety efforts of the operating company reduced the compensation to $15,000 in 1931, $7,000 in 1932, and $3,500 in 1933, and it is understood that the 1934 record is good. The severity rate was 51.0 in 1931 and only 4.8 in 1933.

An outstanding record was made by another mechanized coal mine.[15] A safety engineer was hired in the spring of 1930. The accident cost was high during the first 6 months of the year, averaging 11 cents per ton of coal mined; the cost for the entire year 1930 was 8.0 cents per ton, and the cost per lost-time accident was $260. In 1931 the average cost was reduced to 1.2 cents per ton, and the cost per lost-time accident was $140; during 1932, 1933, and 1934 the costs were held below 1 cent per ton.

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14 Name of company withheld by request.

15 Name of company withheld by request.

The difference in cost of accidents in 1930 compared with 1933 and 1934 is 7.3 cents per ton of coal mined. The accomplishment is the more outstanding because no great financial expenditures were made in bringing about the material reduction of injuries; the responsibility for the safety of the men was placed directly on the shoulders of the supervisory officials, and these officials and the safety engineer have impartially enforced the few safety rules promulgated. When the safety work was started the largest proportion of accidents were from falls of roof, and most of the fatalities were caused by such falls; when reasoning with officials had no apparent effect, a warning was issued that if a man was killed by a fall of roof the officials responsible would be discharged and would not be allowed to act again in a supervisory capacity. Shortly afterwards a man was killed by a roof fall while laying track; the investigation disclosed that within an hour preceding the accident three supervisors had entered the place and had failed to detect the loose roof; they were discharged. Major injuries, such as broken backs, from falls of roof continued, and a ruling was made that if a major injury occurred from fall of roof, the supervisory official would be discharged. Since these rules went into effect fatalities and major injuries from roof falls have been decreased so materially that they appear almost to have been eliminated. The reduction of 7.3 cents per ton of coal in cost of accidents from 1930 to 1933 and 1934 represents much if not all of the difference between profit and loss at the present-day cost of producing coal, and the profit in this case is due largely to increased supervision and discipline with relatively little additional financial outlay for safety.

The chief factor in the reduction of industrial accidents frequently is the dual system of exercising adequate supervision and strict but just discipline; however, this is only part of the main system or organization for "putting over" safety in mining. The safety program of every mining company should include a complete safety organization plan to coordinate safety efforts; safety to be even measurably effective must start at the head of the organization, and the active operating officials must be whole-heartedly behind the promotion of safety and must give a fair amount of their personal time and attention to the work to assure its success. The safety work should be under the direction of a competent safety director or engineer who should devote his entire time to safety promotion. A more or less standard organization has been developed for the mining industry, comprising a chairman, who should be the manager, superintendent, or other ranking official of the company; a secretary, who should preferably be the safety director or engineer; and a membership including all other supervisory officials of the company and representatives of each type of workmen employed. This committee should formulate safety rules, make various kinds of safety inspections and reports, and perform other functions which may lead to the improvement of health and safety in and around the mine.

The mine safety organization should be supplemented by a general safety organization, such as the Holmes Safety Association sponsored by the United States Bureau of Mines, in which all employees, including officials, surface, and underground workers and store and office force, etc., are members. Meetings should be held at least monthly. The Holmes chapter is a medium for assembling all employees in or around the mine monthly and educating them in safe practices as well as calling their attention to unsafe practices.

A large metal mine had an accident cost of $300,000 in 1924, but through safety efforts the cost was reduced to $59,000 in 1930, or a saving in accidents that year of $241,000. Another large metal-mining company decreased lost-time accidents from 1.047 per thousand man-shifts in 1924 to 0.040 lost-time accident per thousand man-shifts in 1930. Still another large metal-mining company operated for 7 years and 3 months without a fatal accident, working a total of 1,192,436 man-shifts. The average yearly cost of compensation per $100 of pay roll in a group of metal mines in a State with high unit payments to the injured in case of accident was $3.04 in 1926, $2.89 in 1927, $2.49 in 1928, and $2.00 in 1929; the saving

in the cost of compensation to these self-insuring mines which entered actively into accident-prevention work was approximately $500,000 in 1929 compared with 1926.

By putting into effect an intensive safety organization and campaign, a Pennsylvania bituminous-coal-mining company in 1 year saved $60,000, or 3 cents per ton of coal mined. The organization of six chapters and the Tenth Bituminous District Council of the Holmes Safety Association in Pennsylvania unquestionably resulted in direct savings to the coal companies; the production of coal by the council members was 5,500,000 tons in 1930 and 4,500,000 tons in 1931. Fatal accidents decreased from 12 to 5; lost-time accidents of 60 days or more decreased from 104 to 77; and accidents involving less than 60 days lost time decreased from 1,007 to 707 in the same period. The increased safety was attributed to the functioning of the Holmes chapters and the activities of the council. After organization of the chapters four of the member mines reduced their accident cost more than half.

The Dehue mine[16] in West Virginia, according to published data, had an exceptionally unfavorable safety record from 1917 to 1927. During this period 36 fatal accidents occurred, an average of 3.3 per year. In 1928, $28,180 in compensation was paid; by 1930, compensation costs had decreased to $12,044; and from January 1 to November 20, 1931 compensation amounted to only $662. The direct cost of accidents in 1928 was 4.6 cents per ton of coal mined, and for 10 1/2 months in 1931 the average cost was 0.25 cent per ton, a reduction of 4.35 cents per ton in 2 years. The estimated indirect cost in 1928 was $112,700, or 18.6 cents per ton; in 1931, for 10 1/2 months, the indirect cost was $2,651, or 1.3 cents per ton. During the 1931 period, $11,050 in direct cost was saved, and the saving in indirect cost was $44,457, or 17.3 cents per ton of coal mined. In 1928 the accident-frequency rate was 185.34, and in 1931 it was 2.77; the accident severity rate was 21.73 in 1928 and 0.822 in 1931. Only one lost-time accident occurred in 1931 to November 20. This record was achieved through the launching of a sincere safety drive based on a definite safety program in which all employees from the ranking operating official to the lowest paid laborer showed keen interest and co-operated fully.

The coal industry is a good example of what safety has done for mining in the United States. In the 5-year period 1906-10 inclusive there were 84 major explosions in the coal mines of the United States, or 17 per year, and the total fatalities from explosions in the coal mines of the United States were 2,388, or 478 per year. As against this ghastly record, there was only 1 major explosion in the coal mines of the United States in 1933, costing 7 lives; there were only 2 major disasters in the coal mines of the United States in 1934, a fire with 5 deaths and an explosion with 17 deaths; and to April 1, 1935 only 1 major explosion occurred in a coal mine, and it cost 13 lives. Surely this is an extra dividend for safety in the operation of coal mines, whether it is figured on a humanitarian basis or on a cold-blooded dollars-and-cents basis, and there is absolutely no doubt that long-continued, well-directed safety work has accomplished this almost miraculous result. Much of the credit is due to the extensive use of permissible explosives, permissible electric equipment, and permissible electric cap lamps in the more dangerous mines. Rock-dusting has unquestionably aided in saving at least 200 lives annually for the past 10 years by preventing widespread explosions through their propagation by coal dust.

The training of approximately 900,000 persons in first-aid in the mining and allied industries in the past 25 years by the field forces of the Bureau of Mines has been responsible for saving at least 200 lives annually for the past 10 years and for instilling safety-consciousness in mine workers, with consequent prevention of at least 10,000 injuries every year (some of which very probably would have resulted in fatalities).

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16 Agee, E. B., Cost of Mine Accidents: Min. Cong. Jour., vol. 18, no. 1, January 1932, p. 32.

This first-aid training and other mine safety activities have reduced fatalities in the coal mines of the United States from 2,658 per year for the period 1906-10, inclusive (or the enormous total of 13,288 for those 5 years), to 1,013 in 1933 and about 1,150 in 1934; moreover, the annual tonnages produced in these years did not differ materially. The fatality rate in the coal mines of the United States per million tons produced in 1933 was only 2.78, or less than half of the 5.89 rate for the 1906-10 period; this is the lowest rate by far in the history of coal mining in the United States. There is reason to believe that safety effort of various kinds, exerted as a result of the admittedly bad fatal-accident record of the coal mines of the United States from 1906-10, inclusive, has resulted in the prevention of at least 1,000 fatal accidents and from 50,000 to 100,000 nonfatal accidents annually since 1910. Surely, safety has produced dividends of the highest and most valuable type by this performance.

COST OF SAFETY WORK

The cost of maintaining adequate safety in a mining property is considerable but certainly is not excessive, and with equal certainty the ultimate cost of neglecting safety in and around mines is heavy not only on the operating company and its employees but also on the entire community.

The explosion in a Welsh coal mine in September 1934 in which 265 lives were lost is a good example of the vast losses whioh accrue to mine workers and their families, the mine owners, the community at large, and the Government, possibly to others, when certain types of accidents occur. Because of fires caused by the explosion most of the 265 dead persons were sealed in the mine a few days after the disaster occurred, and the mine remained sealed until March 1, 1935. Approximately 1,500 workers were thrown out of employment by the closing of this mine, and to aid these unemployed persons as well as the dependents of those who were killed in the disaster a public subscription was taken which aggregated nearly $3,000,000; the operating company has had very great losses in compensation and other similar payments in the 265 deaths, in the enormous damage done to the mine, in the loss of several months' business, and in numerous other ways. Moreover, who can even begin to calculate the vast amount of suffering and misery which the disaster has occasioned among the relatives and friends of the dead persons, as well as the economic losses to these people, to the local tradesmen, and to others due to these deaths and the sealing of the mine for several months, possibly its permanent abandonment? There is reason for the belief that this one accident will ultimately cost at least $5,000,000 and possibly as much as $10,000,000 in money and much more than that in misery and suffering. Probably this amount of money would oover nicely the entire cost of adequate safety work in all of the coal mines of Great Britain for several years.

From 15 to 17 cents per ton seems reasonable as the total present-day cost of coal-mine accidents; inquiries also have been made as to the cost of preventing accidents, but definite data are not readily obtainable as far too many conflicting elements enter into the cost of conducting coal mines to segregate effectively all of those features which pertain to safety. Logically, safety enters very definitely into supervision, ventilation, haulage, timbering, blasting, etc., as well as rock-dusting, first aid, safety organization, safety meetings, and other similar items; however, such items as supervision, ventilation, timbering, haulage, and blasting are an integral part of mine operation, as manifestly no reasonably efficient coal mine under present-day conditions could be worked without these and numerous other functioning agencies or departments. Rock-dusting in some coal mines has taken its place as one of the main operating functions, and in many mines rock-dusting is assessed against operating costs, just as are ventilation, haulage, drainage, blasting, etc.; this is as it should be, and all nonanthracite coal mines should be required to rock-dust as routine daily operating procedure.

While the entire operating personnel, including all officials and workers, certainly should partake actively in accident-prevention activities, up-and-coming mining organizations have for the past several years realized that "what's everybody's business is nobody's business", and that accident-prevention work must be placed in a specific department if accidents are actually to be prevented. Since real accomplishment in maintaining safe operation of mines depends largely on the safety department, it seems fair to take as the cost of accident-prevention work in a coal mine the costs due to this department and its activities, with the knowledge, however, that much safety work, the cost of which goes into the regular working accounts, is done by the operating departments, but that through safety of operation efficiency is increased and costs are lowered.

Table 7 gives data in connection with one study made on the cost of accident-prevention work; the data, however, are by no means as complete as desirable.

TABLE 7.- Cost of accident-prevention work

Item	Mine A	Mine B	Mine C	Mine D	Mine E	Mine F	Mine G
Salaries	...	$1,600.00	...	...	$9,000.00	...	(1/)
First-aid training and supplies	...	232.87	...	...	2,110.00	...	(1/)
Mine-rescue training	...	86.25	...	...	10.00	...	(1/)
First-aid contests	...	...	...	...	1,650.00	...	(1/)
Safety meetings	...	...	...	...	275.00	$0.00150	(1/)
Bulletin boards and posters	...	100.00	$690.00	...	125.00	.00025	(1/)
Bonuses and awards	...	...	25.00	...	...	...	...
Protective clothing	...	50.00	...	...	...	...	...
Cost of insurance per ton	$0.0208	...	...	...	.0275	...	...
Cost of accident prevention per ton	...	.0028	.015	$0.013	.0194	.0020	$0.0125
Miscellaneous costs	60.00	...	75.00	...	1,554.50	.00025	...
Total cost	2,967.51	2,079.12	16,500.00	10,000.00	13,174.00	...	7.500
Production, tons per year	...	...	...	750,000	2,560,030	287,000	...

[1]Separate costs not given.

NOTE.- One company expends 2.6 mills per ton for accident prevention. Another company has an estimated cost of $4,500; production, 1,200,000 per year; cost 0.375 cent per ton. A coal company has a cost of 0.7 cent per ton, including salaries, safety meetings, and rock-dusting. Still another coal company, producing 1,441,695 tons per year, had (1932) a total cost of $3,717.76 or $0.0025 per ton.

TABLE 7.- Cost of accident-prevention work - Continued

Item	Mine H	Mine I	Mine J	Mine K	Mine L	Mine M
Salaries		(1/)	(1/)			(1/)
First-aid training and supplies	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)
Mine-rescue training			(1/)			
First-aid contests	(1/)		(1/)	(1/)		(1/)
Safety meetings	(1/)	(1/)			(1/)	
Bulletin boards and posters				(1/)		
Bonuses and awards					(1/)	
Protective clothing						
Cost of insurance per ton						
Cost of accident prevention per ton	$0.005	$0.007	$0.009	$0.003	$0.005	$0.004
Miscellaneous costs						
Total cost						
Production, tons per year	143,713	210,823	822,337	220,000	220,000	216,000

[1]Separate costs not given.

NOTE.- One company expends 2.6 mills per ton for accident prevention. Another company has an estimated cost of $4,500; production, 1,200,000 per year; cost 0.375 cent per ton. A coal company has a cost of 0.7 cent per ton, including salaries, safety meetings, and rock-dusting. Still another coal company, producing 1,441,695 tons per year, had (1932) a total cost of $3,717.76 or $0.0025 per ton.

One coal-mining company, with one of the best safety records in the history of coal mining in the United States, gave $1,350.00 as the cost of accident-prevention work in the production of about 220,000 tons of coal, or about 0.6 cent per ton. Another company produced about 1,440,000 tons of coal at a cost of $3,700.00 for its accident-prevention work, or about 0.25 cent per ton; the items included first-aid training and bandages, etc., safety bonuses, safety contests, wages and expenses of safety personnel, etc. Still another coal-mining company over a 4-year period produced about 7,500,000 tons of coal, and its records showed an average per-ton cost for its safety department (accident-prevention work) of 0.32 cent; this company shows very good safety accomplishment. Another coal-mining company with a better-than-average safety record produced about 5,200,000 tons of coal, and the books showed the cost of operating its safety department as $0.35 per $100 of pay roll. A coal mine with one of the outstanding safety records in coal mining in the United States placed the cost of its accident prevention work at 0.9 cent per ton on an output of slightly less than 300,000 tons of coal, the cost including salaries, bonuses, safety meetings, first-aid contests, and numerous small items. One coal-mining company, producing about 1,200,000 tons of coal, placed its safety-department expenditures at about $4,500, or about three eighths cent per ton. Another large producer of coal indicated that definite figures were not at hand but that an estimate of 0.75 to 1 cent per ton for accident-prevention work at its mine would be about right; another fairly large producer of coal with a good accident record placed an estimate of 0.25 cent per ton as the cost of its accident-prevention work, that is, its safety-department activities. One company with a production of 725,000 tons placed the cost of its safety work at 0.2 cent per ton, and for several years it has had an excell-

ent safety record; this company reports that in 1927 the costs entering into accident occurrence average 8 to 10 cents per ton but that in 1934 these costs had been reduced to slightly over 2 cents per ton.

The average of the above costs for safety departments in coal mines, most of which have excellent safety performance, is about 0.75 cent per ton, and it seems conservative to use as the average cost of a well-functioning safety department 1 cent per ton of coal produced, although under some conditions the cost may be around or even in excess of 2 cents per ton. This average cost of accident-prevention work in and around coal mines, of course, does not cover such items of accident-prevention work as apply largely to ventilation, timbering, drainage, rock-dusting, haulage, etc., as these items are (and should be) chargeable against production or operating cost; but it can be stated confidently that for every cent devoted by these operating agencies to the forwarding of safety at least an equal cost advantage is secured in efficiency, and some mining organizations state that safety devices, methods, and practices put into effect by or through the operating personnel reduce cost as well as increase tonnage.

For the average mine the cost of the safety department and its activities should be about 1 cent per ton of coal in coal mines, or an average of not more than $1.00 per $100 of pay roll for all types of coal, metal, and nonmetallic mineral underground properties, but the cost for quarries and opencut mines should be considerably less. The cost includes the salaries of safety inspectors; the cost of posters, first-aid equipment, etc.; the expense of training all men in first-aid; and the financing of periodical safety meetings and possibly of a sectional first-aid contest annually. Since figures show that the safety department and its activities cost between about 0.5 cent and 1.5 cents per ton of coal mined and that 1 cent per ton is a fair average cost, these costs usually are less than $1.00 and are rarely as much as $1.50 per $100 of pay roll.

MINE-ACCIDENT COSTS WHERE EFFECTIVE SAFETY WORK IS DONE

The results of the work of an effective safety organization are not obtained readily, but some fairly definite data are at hand. A mine[17] in the Pittsburgh (Pa.) region, by perfecting a safety organization and giving it authority, reduced its compensation, medical, and hospitalization costs from 8 cents per ton of coal mined in 1930 to 0.73 cent per ton for compensation and 1.2 cents per ton for compensation, medical, and hospitalization costs in 1931. Another coal company in the same region, with a well-functioning safety organization and a good safety record, in the production of two thirds of a million tons of coal in 1931 had compensation cost of only 1.3 cents per ton; another company producing over 1,000,000 tons of coal in 1931 had a compensation cost of 1.73 cents per ton. One large producer of coal (with an annual output of about 10,000,000 tons) after having instituted a good safety organization reduced compensation, hospitalization, and medical cost from 4 cents per ton to 1.8 cents. These companies all have actively functioning safety organizations; several other companies operating in the same region without safety departments have compensation costs of 5 to 7 or more cents per ton.

Many coal mines now hold their compensation costs well under 1 cent per ton, and scores of coal, metal, and nonmetallic (both open pit and underground) mines now have compensation, hospitalization, and medical costs of less than 25 cents per $100 of pay roll; many mines have operated for a year or more,[18] in some instances 4, 5, or 6 years, without a lost-time accident, hence with compensation charges essentially nil.

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17 Ryan, J. T., Profits Through Reduction of Accidents: Min. Cong. Jour., vol. 18, no. 9, September 1932, p. 15.

18 Harrington, D., The Joseph A. Holmes Safety Association and Its Awards: Inf. Circ. 6831, Bureau of Mines, 1935, 100 pp.

Well-planned, well-sustained safety organizations and campaigns have reduced unbelievably accident occurrence (frequency, severity, and costs) within the past 10 years and especially within the past 5 years. One company working both coal and metal mines in a recent 5-year period[19] reduced accident frequency 92 percent in its coal mines and 96 percent in its metal mines; a coal mine reduced accident frequency from 89.9 in 1926 to 12.65 in 1930 and accident severity from 10.81 in 1926 to 0.91 in 1930; a metal-mining company reduced accident frequency from 138.33 in 1923 to 5.44 in 1930, or 97.11 percent; a petroleum organization reduced accident frequency from 87.9 in 1926 to 3.3 in 1930; a surface metal mine reduced accident frequency from 121.3 and accident severity from 10.1 in 1922 to 8.6 and 0.2, respectively, in 1931; as a result of a safety drive a company operating several quarries, a coal mine, and a manufacturing plant reduced lost-time accidents from 307 in 1927 to 16 in 1931, or practically 95 percent; a large-capacity coal-mining company reduced accident frequency from 340.15 in 1929 to 74.04 in 1933 and accident severity from 43.74 in 1929 to 2.09 in 1933; a petroleum company decreased frequency from 22.37 in 1927 to 7.67 in 1932, or practically 67 percent, and reduced severity from 4.81 in 1927 to 0.26 in 1932, or about 95 percent; from 1930 to 1933 a coal mine reduced the number of lost-time accidents 92.8 percent, accident frequency 89.2 percent, accident severity 97.2 percent and cost of accidents 91.3 percent; a large coal-mining company operating several mines reduced accident frequency 75 percent from 1929 to 1933; a metal-mining company operating mines, mills, smelters, etc., reduced accident frequency from 188.25 in 1923 to 1.47 in 1933, and during this period its underground mine worked considerably over a year without a lost-time accident; and a similar organization reduced frequency from 64.41 in 1929 to 5.16 in 1933 and accident severity from 10.96 in 1929 to 0.077 in 1933.

From the foregoing and numerous similar records at hand it appears that reducing accident occurrence (including frequency, severity, and cost) as much as 90 percent within a few years through well-directed accident-prevention activities in the mining and allied industries is by no means unusual, and this would appear to warrant a statement that at least 75 percent of the accidents in and around our mines and mining plants can be prevented. That this is not an absurd assumption or one not feasible of accomplishment is substantiated, at least somewhat, by the following statement taken from an interesting publication entitled "Tendencies in Workmen's Compensation", issued by the United States Chamber of Commerce:

> It is not uncommon to find industrial plants over a short period of years reducing accidents from 75 to 90 percent, and there are many plants which have records of several million man-hours without a lost-time accident. * * * The cement industry, which leads all others in point of accident reduction, has made a remarkable record. Out of 150 cement plants, located in all parts of the United States and Canada, 45 finished a recent year without a single lost-time accident among their thousands of employees.

This pamphlet also contains the following rather significant statement:

> Workmen's compensation has been a constant factor in stimulating accident prevention work.

ACCIDENT COSTS AND SAFETY SAVINGS FOR THE EMPLOYER

It thus appears that the present-day cost of accidents in coal mining averages about 20 cents per ton produced, that many progressive mining companies in a very few years (certainly within 5 years) have reduced their accidents as much as 90 percent and some by 95 or more percent, and that by well-directed effort at least 75 percent of the present-day rate of

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19 See footnote 18.

accident occurrence in and around mines can be eliminated; hence it can be stated conservatively that accidents should cost our coal mines not more than 5 cents per ton instead of approximately 20 cents as at present, and this means that real mine safety work may save about 15 cents per ton. On the 1934 coal output of about 415,000,000 tons for the United States, this would amount to a dollars-and-cents saving of nearly $62,000,000, certainly a handsome "dividend" readily available to our coal-mine operators whenever they can be induced to "get down to brass tacks" in connection with safety in the operation of the coal mines of the United States.

If the economic phase of safety in mining is viewed on the basis of percentage of production cost of the country's mineral output due to accidents it seems reasonable to believe that at least 10 percent of the cost of production of raw minerals is due in one manner or another to accident occurrence. Domestic raw mineral production in 1934 is supposed to have had a value of about $2,500,000,000, and if 10 percent of this was chargeable to accidents the mineral-production accident bill for 1934 was about $250,000,000; if this can be reduced 75 percent (and there is the best of reasons to believe that it can) the saving would amount to $187,500,000. This sizable dividend is available to the mining industry of the United States whenever the leaders in that industry finally bring themselves to exert the personal effort and financial outlay necessary for real safety achievement. A relatively light financial outlay would bring about this desirable result, as the mining companies with outstanding safety records indicate that maintenance of an effective safety organization and plan requires an outlay considerably less than 1 percent of the cost of production, usually being less than 1 cent per ton in coal mining and less than $1.00 per $100 of pay roll in other types of mining.

ACCIDENT COSTS AND SAFETY SAVINGS FOR THE WORKER

Practically all of the foregoing discussion on economic aspects of accident occurrence in mining has been confined to the effect on the owner or operator, but the effects on the worker, both humanitarian and economic, are far more vital than those on the employer. No estimate can ever be made as to the cost of the enormous amount of human suffering and misery involved in the 2,000 to 3,000 fatalities and 100,000 to 150,000 or more nonfatal accidents that have occurred annually in and around mining operations in this country, and only rough approximations can be made as to the dollars-and-cents cost of these accidents to the worker and those dependent on him.

It has already been indicated that the slow but definite reduction in fatality rate in domestic coal mines in the past 24 years has very probably saved about 25,500 lives and at least 1,275,000 nonfatal coal-mining accidents. The average age of the coal miner who is killed is about 35 years, and under normal conditions he should earn at least $1,000 per year and have a wage-earning life expectancy of 20 years; hence in that period he would receive $20,000 for his services. Therefore, the saving of the lives of about 25,500 coal-mine workers in the past 24 years has prevented a financial loss to them and their families of around $510,000,000.

In the prevention of 1,275,000 nonfatal accidents during this 24-year period the coal miners and their friends and families have been saved not only a vast amount of suffering and misery but also enormous financial loss. It is now thought that the average cost of a nonfatal accident to the employer is about $300, and of this about two thirds or three fourths is the amount paid to the injured person. If the average amount paid to the injured man for nonfatal compensable injuries is $200, then the amount received by injured persons for 1,275,000 of these injuries would be $255,000,000. However, investigations now indicate that for every dollar received in compensation for injuries the injured man suffers a loss of at

least $3 (and some investigators place the loss as high as $5) in loss of wages and other losses and costs. Hence, if $3 or the lowest figure is accepted, the workers have been saved $765,000,000 in the nonfatal compensable accidents which it is estimated have been prevented by greater safety in coal mines of this country during the past 24 years.

Unquestionably, there have been additional enormous savings to coal-mine workers in the prevention of millions of noncompensable nonfatal injuries during the past 24 years, and even if these are omitted the savings to coal-mine workers by the prevention of fatal and nonfatal compensable injuries for these 24 years totals $1,275,000,000, or more than $73,-000,000 per year. If to this total were added the very material savings through prevention of noncompensable, nonfatal accidents (the financial burden of which falls more heavily on the injured person than on the employer) doubtless our coal-mine workers have benefitted financially at least $100,000,000 annually by the greater safety in coal-mine operation since 1910.

Similar savings have been made by workers in the various other branches of the mining and allied industries, and it appears from known facts that the annual dollars-and-cents savings to mine workers (coal, metal, nonmetallic, etc.) in the greater safety of mine operation now as against that 25 years ago is at least $200,000,000 per year, or about $200 per year for every one of the approximately 1,000,000 persons now engaged in the various types of mining. Certainly the mine worker has a much more vital interest in the forwarding of safety in mine operation than has the operator, because the worker must endure the physical pain and suffering from accidents, also his individual financial losses from accidents and gain through their prevention are far greater than the similar gains or losses of the employer.

CONCLUSION

Instead of being the "fad" which far too many of those engaged in mining have always considered safety effort or safety "preachments", the prevention of accidents now is becoming known as one of the most vital economic features in the production of our mineral products, and there is reason to believe that few if any phases of mining have greater possibilities in relatively quick and effective reduction of production costs and increase in working efficiency than have the installation and strict maintenance of an up-to-date safety procedure in and around our mines and mining plants.

After this report has served your purpose and if you have no further need for it, please return it to the Bureau of Mines. The use of this mailing label to do so will be official business and no postage stamps will be required.

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October 1935

Department of the Interior

UNITED STATES BUREAU OF MINES
John W. Finch, Director

INFORMATION CIRCULAR

SAND AND GRAVEL EXCAVATION;

PART 4: CAR AND LOCOMOTIVE HAULAGE; HOIST AND ROPE HAULAGE; REMOTE-CONTROL HAULAGE;

BY

J. R. Thoenen

ERRATA SHEET

I.C. 6856, Issued Oct., 1935

Page 149 now reads

$$T = 4 \times \frac{\pi d^2 PS}{4\pi D} = \frac{\pi d^2 PS}{D}$$

should read

$$T = 4 \times \frac{\pi d^2 PS}{4\pi D} = \frac{d^2 PS}{D}$$

Page 153, seventh word, second line should be <u>mean</u> instead of <u>men</u>.

Page 157, formula at bottom reads

$$\frac{5730}{15} = 19.54 \text{ miles per hour}$$

should read

$$\sqrt{\frac{5730}{15}} = 19.54 \text{ miles per hour.}$$

Page 175, formula reads

$$S = \frac{\sqrt{8DT}}{W} = \frac{\sqrt{8 \times 1 \times 10000}}{488} = 164 \text{ feet}$$

should read

$$S = \sqrt{\frac{8DT}{W}} = \sqrt{\frac{8 \times 1 \times 10000}{488}} = 164 \text{ feet.}$$

I.C. 6856,
October 1935

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SAND AND GRAVEL EXCAVATION - PART IV:[1] CAR AND LOCOMOTIVE HAULAGE; HOIST AND ROPE HAULAGE; REMOTE-CONTROL HAULAGE

By J. R. Thoenen[2]

INTRODUCTION

This circular is part IV of the third paper (entitled "Sand and Gravel Excavation") of a series summarizing the technical problems involved in the production and preparation of sand and gravel. Part I discussed the use of power shovels, draglines, and excavator cranes; part II discussed the use of power scrapers, slackline cableway excavators and hydraulic monitors; and part III discussed the use of hydraulic, clamshell, ladder, and dipper dredges. This circular discusses haulage equipment in general, particularly the use of industrial cars with locomotives or hoists as the motive power. Part V, to follow, will discuss the use of other types of haulage equipment.

HAULAGE EQUIPMENT

Haulage equipment as used at sand and gravel pits may be divided into three classes: (1) That used to receive overburden and transfer it to the waste dump; (2) that used to receive sand and gravel from the digging unit and transfer it to the treatment plant. Where the digging unit is also the treatment plant the haulage unit transfers from the digger to points of distribution; (3) that used to receive sand and gravel from the plant and transfer it to storage, to recover it from storage and return it to the plant for further treatment, or to recover it from storage and transfer it to shipping equipment.

Haulage equipment in the first class has been discussed in a previous paper but not in as great detail as herein. A study of the function of haulage equipment in the third class belongs in a paper designed to follow this and hence will not be discussed here. This paper will deal directly with the function of haulage equipment in the first and second classes, namely, that used to handle overburden, receive sand and gravel from the digger, and transfer it to plant or points of distribution.

Except for the power scraper, cableway excavator, hydraulic dredge, and hydraulic giant, excavator units themselves do no hauling, and at times even these units depend on supplementary haulage equipment. With the exceptions mentioned, excavation units depend upon the haulage unit for efficient operation.

Haulage units cannot transfer material that has not been dug. Therefore haulage equipment is subordinate but complementary to excavation equipment. This requires that the haulage unit must be carefully coordinated to serve the digger properly. The first and most important consideration is coordination in capacity. Capacity does not mean the size of the vehicle but the ability of the unit to receive the required tonnage from the digger and to deliver it over the necessary haulage route to the plant or distribution point in the re-

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U.S. Bureau of Mines Information Circular 6856."

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quired time. Regardless of the type of haulage unit selected, the problem of capacity is of prime importance, and on its correct solution depends the proper balance of operation in delivering material to the treatment plant.

Selection of the proper type of haulage unit depends upon other factors, such as the type of excavator, the mining method, the surface topography, the character of the material mined, the power available, and the past experience and preference of the operator.

The types of haulage units used with various types of excavators are as follows, preference being shown by order of mention.

1. With power shovels and draglines: Industrial cars and locomotives; autotrucks; industrial cars and hoists; conveyor belts.

2. With cranes: Industrial cars and locomotives; autotrucks.

3. With power scrapers and cableway excavators: These types usually do their own haulng, but each may supplement the other or a like unit. In rare instances each may use cars or autotrucks.

4. With hydraulic dredges: Pumps and pipe lies; barges; power scrapers; cableway excavators.

5. Clamshell, ladder, and dipper dredges: Barges.

6. Hydraulic giants: Sluices; pumps and pipe lines.

The effect of the method of mining on the haulage equipment to be used will closely parallel its effect on the excavating unit, since the method used is generally planned to suit the unit. However, varying methods may change the order of preference as follows:

1. High banks may require conveyor belts in preference to either cars or autotrucks.
2. Thin deposits of wide area may require autotrucks in preference to other types.
3. Deep, dry pits may require hoists in preference to locomotives.
4. Thin beds in wet pits may require barges in preference to pipe lines.
5. River deposits may require barges in preference to pipe lines.
6. Lake and ocean deposits may require self-propelled dredges in preference to a separate transportation unit.

The character of the surface may be such as to prohibit the expense of establishing roadbeds for cars operated on tracks whereas autotrucks could be used. For very rough country a combination of cars or trucks with an aerial tram may be necessary. Hoists may be necessary to raise or lower the material to the plant.

Wet pits may require power scrapers or cableway excavators in conjunction with cars or trucks or even aerial trams. The supplementary units are seldom required unless the pit is considerable distance from the plant.

High river banks may necessitate barge haul even though the hydraulic dredge is located close to the plant. Swift river currents may prevent the use of floating pipe lines and necessitate barge haul. To avoid the effect of swift currents pipe lines are sometimes submerged and laid on the river bottom.

The character of the material may have an important bearing on the type of haulage unit selected. An excess of large boulders requires heavy construction of the haulage unit and may require larger units.

An excess of clay may require pumps and pipe lines in preference to barge haul in order to wash the material more thoroughly before it enters the plant. If many large boulders occur with the clay the pipe line may have to give way to barges because of excessive wear. Wet material from pit or marine deposits may require structural differences in the haulage unit which would not be necessary with dry material. Well-rounded sands and gravels may be pumped easier than sharp-edged or flat particles. The shape of individual particles may differentiate between pipe lines or barge haul.

The type of power available has a direct bearing on the type of haulage unit. With cheap current electric locomotives of the trolley or storage-battery type may offer the best

possibilities. Under the same conditions cheap power may warrant transportation with one or more booster pumps rather than barge haul. Scarcity or high cost of coal may require that gasoline or Deisel locomotives or hoists be used instead of steam units. High power costs may indicate that conveyor belts are best in spite of otherwise adverse conditions. Lastly, the past experience and preference of the operator will largely influence the type of haulage unit selected.

It is evident that the factors affecting the type of haulage unit to be used are largely local and vary with individual deposits. Therefore, the choice of type is individualistic and impossible of standardization.

So many designs are available in the different types of haulage equipment that construction details can be discussed only generally. The advantages or disadvantages of general variations in type will be presented, but the principal discussion under the several types will relate to their capacity and methods of calculating capacity.

Since the greatest efficiency is obtained when excavating equipment is operated continuously at or near working capacity, the haulage unit must assure equal or greater capacity under adverse haulage conditions. The determination of capacity in the haulage unit involves such factors as the length of haul; vehicle size and number; motive power and speed; and conditions as to track gage, curves, and grades.

Vehicle size and number, motive power and speed, and track gage and curves require no explanatory definition. Length of haul is defined as the distance between excavator and dump measured over the haulage route in the direction of the loaded haul. In circular or elliptical haulage routes the loaded haul may temporarily exceed the empty return, but this is usually equalized by reverse conditions as the excavator moves. Length of haul in such cases is usually considered as the average loaded haul between excavator and plant. With conveyor belts, aerial trams, and barges the loaded haul and empty return are equal, but with pipe lines there is, of course, no return.

Grades are considered favorable or adverse, depending upon whether the loads move downhill or uphill.

Industrial Cars

Industrial cars operating on steel rails are probably the most popular form of pit haulage used in connection with mechanical excavators. Built in a multiplicity of designs and sizes they can be adapted to any production requirements within the physical limitations of this type of transportation. They have the common disadvantage of requiring rails and ties and a maintained roadbed. This limits their flexibility to a certain extent, although the provision of rails or track in short portable sections reduces the time lost in shifting. As a general rule the heavier the car the greater care must be exercised in roadbed construction and maintenance.

Cars may be pushed by hand or hauled by animals, locomotives, or hoists, or they may have their own motor equipment. When pushed by hand they are handled as single units and seldom exceed a payload capacity of 3 tons. Handled by horses or mules they may be coupled in trains of two or more cars, but the gross weight of trains seldom exceeds 10 tons. For locomotive or hoist power, cars may range in payload from a few tons to standard railway equipment of 100 tons each. Cars may be handled singly or in trains by locomotives, but hoists more often are limited to single cars. The number of cars in a train for locomotive haul is limited by the size and power of the locomotive and the grade and curvature of the track. Self-propelled cars are operated as single units but may range up to 50 tons or more in pay load.

While track gage usually increases with the gross weight of the car or train, the increase is not always proportionate. Cars of relatively large capacity have been designed and

used successfully on narrow-gage tracks, but such requirements are usually caused by some specific local condition.

The ability to use any number of cars in a train within the limit of the size and power of the locomotive permits a wide flexibility in the capacity of the system in that increased tonnage requirements may be accommodated by adding one or more cars to a train. A further increase may be met by replacing the locomotive with a larger unit or by the addition of another locomotive and train.

The substitution of hoists for locomotive power is usually caused by excessive grades. Hoists are used in two ways - as a power unit to pul loaded cars up an incline and as a simple brake mechanism to lower loads on an incline. In either case the hoist may be of the double-drum type with two cables or the single-drum type with one cable, one end of which is payed off the top of the drum while the other end winds on at the bottom. When hoisting loads on one cable or one end of the single cable the other is attached to and lowers the empty car. When used as a brake mechanism the descending loads furnish power to bring up the empty.

Where inclines are necessary, some form of pit haulage is usually employed to bring the loaded cars from the excavator to the foot or top of the incline. This initial haul may be either by hand, animal, locomotive, or autotruck. If the latter is used the truck usually dumps its load to a hopper from which the car or skip on the incline is loaded.

As a comprehensive discussion of the structural details of pit cars would fill a volume it cannot be included in a paper such as this. The reader is referred to manufacturer's catalogs for such details.

Other things being equal, the length of haul has a direct bearing upon the capacity of a haulage unit using cars and locomotives or cars and hoists. For the same size and number of cars the capacity will diminish as the length of haul increases, although not in direct proportion. In computing the effect of haulage length one must consider the completed round trip as a unit, and this must be split into several component parts such as the time required for loading, hauling to plant, dumping, returning empties to digger, and waiting at digger or dump. The loading, dumping, and waiting time for similar units in a single pit are apt to be fairly equal per haulage cycle, irrespective of whether the length of haul is 100 or 1,000 feet. Moreover, the time required to start and accelerate as well as to brake and stop a trip are apt to be fairly uniform and independent of the length of haul. The time required to haul loads is apt to be greater than that to return empties, even though both in- and out-haul distances are equal.

Long hauls ordinarily exceed shorter ones in the initial construction cost per foot because they are usually built to remain in place for longer periods and hence are better alined and ballasted. Operating costs per ton-mile on long hauls are usually less because speeds are higher and maintenance expense is less. Short hauls on frequently shifted tracks, which cannot be heavily ballasted or are crooked and poorly alined as to curves, require heavy maintenance expense.

Other things being equal, on a long haul it is usually more economical to use fewer large cars and faster locomotives rather than the same load capacity in small cars.

Large cars are as a rule easier to load by mechanical equipment than small cars because less time is required to spot the bucket or dipper over them so as to prevent spillage. While more time will be required to load a large car, the loading time per ton of payload may be reduced. However, spotting is as much a function of the locomotive as the digger.

Low cars are easier to load than high cars, since the bucket or dipper need not be raised so high to clear the sides. Low cars also lower the center of gravity and thereby reduce the derail hazard.

Generally long cars with long wheel bases are more difficult to derail and likewise are harder to replace once they jump the track. They also require curves of greater radius. However, this depends upon whether the car has 4 or 8 wheels and whether the trucks are rigidly connnected to the car body.

Large-capacity cars with the same number of axles offer less frictional resistance per ton of payload than small cars. The payload in a large car is concentrated and supported on 4 to 8 journals or bearings, while the same load hauled in smaller cars would be distributed in more cars having from 4 to 8 bearings for each car, each of which contributes frictional resistance. However, the type of bearing may reverse this condition. For instance, a 50-ton car on plain cylindrical bearings in poor condition will afford more resistance than two 25-ton cars fitted with roller bearings.

Larger cars reduce the number of cars in a train for the same payload and hence reduce dumping time per trip, also loading time if the time required to move the train to spot the empty, is more than the excavator time cycle. Shorter trains are also easier to manipulate over the ordinary poorly ballasted pit tracks.

Side-dump cars are commonly built with a center hinge so that they may be dumped to either side. These provide more operating flexibility but usually afford less running stability than those built to dump to one side only. Where the haulage route is a circle or ellipse and the equipment moves continuously in one direction, cars which dump to one side only have often been found to be time savers. Usually they are more easily adapted to automatic dumping mechanisms and can even be arranged to dump without stopping as the car passes the hopper. They lose their advantage where it is necessary to move the equipment in more than one direction, as on a circular pit track with a switch-back to the dump, for to do so the cars must be turned around or arrangements made for dumping on either side of the track.

A surplus of car equipment over maximum needs provides means of reducing time loss due to repairs. Any unit needing repairs can be shunted to the repair track and replaced by another. Thus, the haulage system is not held up by repairs to each unit. This has the effect of giving preference to more small cars than a few large ones.

The power required to move a car or train of cars is equal to the resistance offered by the car or train. The resistance offered by a train is that required (1) to overcome the inertia of standing equipment, (2) to accelerate from one speed to another, and (3) to maintain any attained speed. The resistance offered by inertia will range from 1 1/2 to 5 or more times the running resistance. It will be greater in cold weather, on dirty track, and after prolonged standing of cars.

The resistance offered by the inertia of a standing train is usually omitted in computing the locomotive power for gravel-pit practice, because the inertia of the train is seldom exerted as a single unit. Instead, the inertia of each car is overcome separately. There is always a certain amount of slack in the couplings between cars. In common practice the locomotive is first reversed and the cars are pushed together. When the locomotive then moves ahead, it starts the first car as a single unit. The momentum of the first car helps to start the second and so on as the slack is taken up in each coupling. In this way, train inertia is overcome a single car at a time. If the cars in a train were coupled tightly with no slack in the couplings, the locomotive usually employed would seldom be able to start a loaded train. For this reason, in practice it is easier to start a given pay load in a number of small cars than the same load concentrated in fewer large cars. This practice cannot be used with cars having no brakes if they must be started on an adverse grade.

The theoretical resistance due to acceleration can be computed from the following formula:

$$P = 70.22 \frac{(V^2 - v^2)}{S}$$

in which

P = resistance per ton of gross train weight, in pounds;
S = distance between two points at which velocities are v and V, in feet;
v = initial veloity (for a train at rest v = 0), in miles per hour; and
V = final velocity, in miles per hour.

The time consumed in accelerating to the required speed in the designated distance may be computed from the following formula:

$$P = \frac{95.6\ V}{t} \text{ or } t = \frac{95.6\ V}{P}$$

Table 42 has been computed from these formulas to show the accelerative force P necessary to impart varius velocities within various distances to 1 ton of gross load exclusive of frictional or other resistances and the time t required, in seconds.

TABLE 42.- Accelerative force, pounds per ton (P), and time (t), seconds

Distance, feet	Velocity, miles per hour																			
	3		4		5		6		7		8		9		10		15		20	
	P	t	P	t	P	t	P	t	P	t	P	t	P	t	P	t	P	t	P	t
100....	6.3	45	11.2	34	17.5	27	25.3	23	34.4	20	45.0	17	56.7	15	70.0	14	158	9	281	7
150....	4.2	68	7.5	51	11.7	41	16.8	34	23.0	29	30.0	26	38.0	23	47.0	20	105	14	187	10
200....	3.2	90	5.6	68	8.8	54	12.6	46	17.2	39	22.5	34	28.5	30	35.0	27	79.0	18	140	14
250....	2.5	115	4.5	85	7.0	68	10.1	57	13.8	49	18.0	43	22.7	38	28.0	34	63.0	23	112	17
300....	2.1	137	3.7	103	5.8	82	8.4	68	11.5	58	15.0	51	19.0	45	23.4	41	52.5	27	93.5	20
400....	1.6	180	2.8	137	4.4	109	6.3	91	8.6	78	11.2	68	14.2	61	17.5	55	39.5	36	70.0	27
500....	1.3	220	2.2	174	3.5	137	5.0	115	6.9	97	9.0	85	11.3	76	14.0	68	31.5	46	56.3	34
600....	1.1	260	1.9	200	2.9	165	4.2	137	5.7	117	7.5	102	9.5	91	11.7	82	26.4	54	46.7	41
700....	.9	320	1.6	240	2.5	191	3.6	160	4.9	137	6.4	120	8.1	106	10.0	96	22.5	64	40.0	48
800....	.8	360	1.4	273	2.2	218	3.2	180	4.3	156	5.6	137	7.1	121	8.8	109	19.5	74	35.0	55
900....	.7	410	1.2	320	1.9	252	2.8	205	3.8	176	5.0	153	6.3	137	7.8	123	17.5	82	31.2	61
1,000....	.6	478	1.1	348	1.8	266	2.5	230	3.4	197	4.5	170	5.7	151	7.0	137	15.8	91	28.1	68
1,500....	.4	720	.7	510	1.2	400	1.7	338	2.3	291	3.0	255	3.8	227	4.7	203	10.5	137	18.7	102
2,000....	.3	960	.6	638	.9	530	1.3	440	1.7	394	2.3	333	2.9	297	3.5	273	7.9	182	14.0	137

Example 5. What accelerative force will be required to bring a standing train of 10 cars to a speed of 10 miles per hour in a distance of 1,000 feet if each car weighs 5 tons and carries 12 tons of payload?

Total train weight....................................	tons	170
Accelerative force per ton for 10 miles per hour and 1,000 feet, from table 42....	pounds	7.0
Total force required........................	do.	1,190.0

Example 6. What accelerative force will be required to bring the train of example 5 running at 10 miles per hour to a speed of 15 miles per hour in 500 feet? From table 42:

		Pounds
Force for 15 miles per hour	500 feet	31.5
Force for 10 miles per hour	500 feet	14.0
Increased force per ton....................		17.5

Total force equals 170 x 17.5 = 2,975 pounds.

This means that in addition to the drawbar pull necessary to move the train the locomotive would have to have an extra pull of 1,190 pounds to attain a speed of 10 miles per hour in 1,000 feet and 2,975 pounds to accelerate to 15 miles per hour in the next 500 feet.

The resistance offered by a running train is the cumulative effect of a number of factors, such as (1) wind resistance, (2) lubrication, (3) oscillation and concussion between wheels and rails, (4) rolling friction between wheels and rails, (5) journal friction between axles and boxes, (6) track grade, and (7) track curvature.

In sand and gravel pit operation the first five factors are impossible of determination with mathematical precision. This is true because of the multiplicity of car, wheel, and journal design, rail used, and track lay-out. Generally wind resistance will be negligible because of the comparatively low speeds. Lubrication will range from poor to medium, with few conditions comparable to good railway operation. Oscillation and concussion will vary with the square of the velocity. Their determination independent of other resistances cannot be computed, but because of the necessarily poor alinement and the condition of pit tracks they will be at a maximum. Rolling friction has not been definitely determined independent of other friction factors. It depends upon the rigidity of the rail and the support given by the ties. For the same reason this also will be high. Journal friction per ton of load is less for higher pressures or heavy wheel loads, greater for very low or high speeds, a minimum for train speeds of about 10 miles per hour, and less in warm weather. Obviously, all local conditions must be known before calculations can be made.

These factors are more definite and can be fairly closely evaluated after experiment and trial for standard railway equipment and conditions, and some laboratory experiments have been made on coal-mine equipment.[3]

Various formulas have been compiled by different authorities from which to compute the resistance of a train due to its speed, but none can be used accurately under the varied conditions of sand and gravel operations. Train resistance over a particular section of track or at a particular point is determined most accurately by the use of a dynamometer car connected between the locomotive and the train. This car is equipped with electrical instruments which make a graphic record of the exact total force used in moving the train. By the use of such devices experiments have shown that pit haulage on level track requires a drawbar pull ranging from 10 to as high as 60 pounds per ton of gross train weight. The minimum of 10 pounds may be said to apply where cars in good condition are operated over straight, well-ballasted tracks. Except under the worst car and track conditions, it is doubtful if more than 40 pounds per ton will be required. The same experiments also show that there is little difference in train resistance when running at 5 to 10 miles per hour, although at lower velocities the resistance increases. In common practice, pit haulage in sand and gravel operations seldom will average over 10 miles per hour, although in some instances higher speeds are used for short distances to build up momentum to carry the train over short, steep grades.

Train resistance for gravel-pit haulage may be taken as ranging from 10 to 40 pounds per ton of gross weight, but it may increase to 60 pounds under particularly adverse conditions.

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3 Hersey, M. D., and Wetzel, H. E., Mine-Car Friction as Influenced by Wheel Diameter and Other Variables: Carnegie Inst. Technol. Bull. 13, 1924, pp. 35.

Hersey, M. D., Shove, H., and Downes, M. S., Mine-Car Friction with Six Types of Trucks: Carnegie Inst. Technol., Bull. 20, 1925, pp 33.

Example 7. The 10-car train used in example 5 might offer a running resistance as low as

$$10 \times 170 = 1{,}700 \text{ pounds,}$$

or might under extreme conditions require

$$60 \times 170 = 10{,}200 \text{ pounds,}$$

but ordinarily it would not exceed

$$40 \times 170 = 6{,}800 \text{ pounds.}$$

Train resistance due to grades can be computed accurately, since it varies only with the grade. Track grades are expressed in various ways, such as percentage, feet rise in 100 feet horizontal advance, degree (degree of angle above horizontal), and feet per mile. Table 43 shows the equivalents of these methods of expression.

TABLE 43.- Grade equivalents

Percent	Feet per 100 feet	Degrees		Feet per mile
1/4	0.25	0°	9'	13.2
1/2	.50	0°	17'	26.4
3/4	.75	0°	26'	39.6
1	1.00	0°	35'	52.8
2	2.0	1°	10'	105.6
2 1/2	2.5	1°	30'	132.0
3	3.0	1°	45'	158.4
3 1/2	3.5	2°	0'	184.8
4	4.0	2°	20'	211.2
5	5.0	3°	0'	264.0
6	6.0	3°	20'	316.8
7	7.0	4°	0'	369.6
8	8.0	4°	45'	422.4
10	10.0	5°	45'	528.0
12 1/4	12.25	7°	0'	647.0
14	14.0	8°	0'	740.0
16	16.0	9°	0'	845.0
18	18.0	10°	6'	950.0
20	20.0	11°	20'	1,056.0
25	25.0	14°	0'	1,320.0

The formula to be used in determining the resistance due to grade will depend upon how the grade is expressed.

Percent	$R = 20\ n$
Feet per 100 feet	$R = 20\ F$
Degree	$R = W$ sine angle
Feet per mile	$R = 0.379\ H$

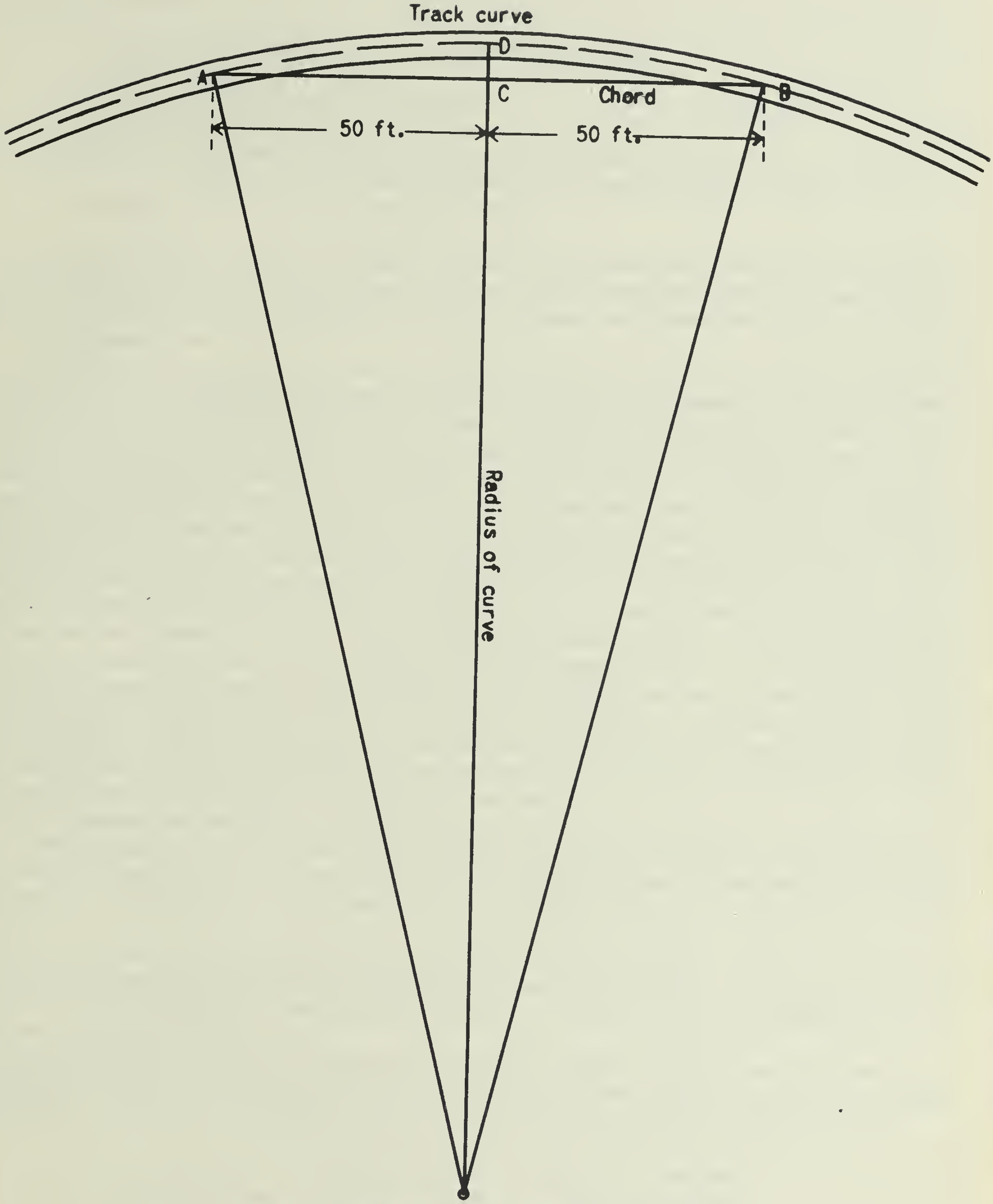

Figure 15.- Method of curve measurement.

In these formulas

R = pounds of resistance per ton of gross train weight,
n = number of percent,
F = feet rise in each 100 feet advance,
W = 2,000 pounds of gross train weight,
Sine angle = natural sine of the angle of inclination or
height rise in feet divided by the inclined length in feet, and
H = height of rise in each horizontal mile.

Calculation shows that up to a 10-percent grade the resistance is exactly 20 pounds per ton of gross train weight for each percent of grade. Thus, the resistance to 1 ton of gross load on a 1/4-percent grade will be 20 x 1/4 = 5 pounds; on a 5-percent grade it will be 20 x 5 = 100 pounds; etc.

The resistance due to track curvature depends upon the friction of the wheel flange on the outer rail, the compensating elevation of the outer rail, the length of the wheel base of the car, whether the wheels are solid or loose on the axles, whether the trucks are free to turn or rigidly attached to the car, the velocity of the car, and the track gage.

Because of these factors curve resistance cannot be reduced to mathematical precision but must be ascertained experimentally, as with the dynamometer car. Published results of experimental data are scarce. University of Illinois Engineering Experiment Station Bulletin 167 shows curve resistances ranging from 0.41 to 0.64 pound for freight trains on 1° and 3° curves or an average of 0.5 pound per ton per degree of curve. Another authority (anonymous) showed 21 pounds friction per ton for a single car due to a curve of 85-foot radius, or 0.3 pound per ton per degree of curve. He also found a 20-car train on a curve of 350-foot radius gave 7 pounds per ton or 0.4 pound per ton per degree of curve. Other investigators find curve resistances ranging from 0.5 pound to 1.72 pounds per ton per degree of curve. Authorities are inclined to agree that, for permanent track, curve resistance should be computed as ranging from 0.5 to 0.8 pound per ton per degree of curve. For temporary or movable track such as that found in gravel pits the resistance will be higher, and probably not less than 1 pound per ton per degree of curve should be used.

Railway curves are designated by degree of curve or radius of curve. The radius of the curve is the distance from the center line between the rails to the center of the circle of which the curve is an arc. The degree of the curve is the number of degrees in the angle subtended by a chord 100 feet long measured in a straight line between two points on the curve.

Figure 15 shows a railway curve with the parts mentioned indicated. The curve shown is a 28° curve, as measured by the angle subtended by the 100-foot chord, and has a radius of 206 feet. A convenient way of measuring the radius of a curve without locating the center of the circle is as follows:

As in figure 15, measure the distances AC and CD in inches. Multiply each by itself and add together. Divide this sum by twice the length CD in inches. This will give the radius of the curve in inches. The example shown in figure 15 will work out as follows:

AC = 50 feet = 600 inches;	600 x 600 =	360,000
CD = 6 feet 2 inches = 74 inches;	74 x 74 =	5,476
Add =		365,476

Twice CD = 148 inches.
365,476 ÷ 148 = 2,470 inches or a radius of 206 feet.

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Care must be exercised to see that the line AB, as laid out, is straight and that CD is measured accurately, as an error of a fraction of an inch here may make a difference of as much as 1°.

Distance AB may be measured on the inner rail rather than on the center line of the track and may be any convenient distance down to, say, 20 feet for sharp curves. Measurements should be made from and to the same part of the rail in each case.

For approximate calculations the measurements can be made in feet using the following formula:

$$\text{Radius} = \frac{(AC)^2 + (CD)^2}{2\ CD}$$

Table 44 has been compiled to show the degree of curvature corresponding to the length of radius.

TABLE 44.- Degree and radius (feet) of curves

Curvature, °	Radius	Curvature, °	Radius	Curvature, °	Radius
1	5,730	21	273	41	139
2	2,866	22	260	42	136
3	1,910	23	249	43	133
4	1,432	24	238	44	130
5	1,146	25	229	45	127
6	955	26	220	46	125
7	818	27	212	47	122
8	716	28	206	48	119
9	636	29	197	49	117
10	573	30	191	50	114
11	521	31	185	51	112
12	477	32	179	52	110
13	441	33	174	53	108
14	409	34	169	54	106
15	382	35	163	55	104
16	358	36	159	56	102
17	337	37	155	57	100
18	318	38	150	58	98.9
19	301	39	147	59	97
20	286	40	143	60	95.5

The total resistance offered by a car or train is, then, the sum of the resistance due to (1) acceleration, (2) rolling and journal friction, (3) grade, and (4) curvature.

Example 8. What is the total resistance offered by a train of 10 gravel cars each weighing 5 tons and carrying 12 tons of pay load running at 10 miles per hour on a 2-percent grade and a 3° curve? It is assumed that cars and track are in average condition.

The gross weight of the train is 10 x 17 = 170 tons.

	Pounds
Rolling resistance, 170 x 30	5,100
Resistance due to grade, 170 x 20 x 2	6,800
Resistance due to curve, 170 x 3 x 1	510
Total	12,410

If the train must reach this speed in a distance of 2,000 feet, resistance due to acceleration (table 42) is then

$$170 \times 3.5 = 595 \text{ pounds.}$$

If the train starts and continues the whole 2,000 feet on the grade and curve above, the total resistance will be 12,410 + 595 = 13,005 pounds.

The starting resistance of the train as a unit at the instant of starting under good conditions may be

$$13{,}000 \times 1\ 1/2 = 19{,}500 \text{ pounds,}$$

but under adverse conditions it may be as much as

$$13{,}000 \times 5 = 65{,}000 \text{ pounds.}$$

In other words, this is the drawbar pull necessary to be exerted by the locomotive if the train is started as a unit and is exclusive of the force necessary to move the locomotive itself. However, as stated before, the starting resistance is usually omitted in computing drawbar pull for pit locomotives.

The speed available from the motive power is usually of secondary importance, because it is seldom that pit tracks are in condition to permit the maximum speed of the locomotive. On permanent tracks for long hauls, however, conditions are different, and the speed of the equipment becomes important in reducing the haulage cycle.

LOCOMOTIVE POWER

The motive power and speed of the locomotive or hoist probably has more effect on the capacity of a haulage system than any other element.

Locomotive design ranges from the machine which has comparatively low drawbar pull but which easily maintains high speeds to the heavy, slow-speed engine capable of starting heavy loads.

Details of design vary with the type of power or fuel used, gage of track, and nature of the work to be done. Generally, long, level hauls use lighter locomotives capable of higher speeds.

Ordinarily in sand and gravel pits locomotive speed is sacrificed for power. In fact, in many installations the locomotive is provided with a governor by which the speed is held to a predetermined maximum.

The function of a locomotive is to provide power for moving. To do this with greatest efficiency it must be in motion the greatest possible percentage of operating time. Thus, delays of any nature either at the digger, dump, or enroute impair locomotive efficiency.

Proper selection of a locomotive requires intensive study of all local conditions, with particular attention to the length of haul; gross load per trip; and condition of the track as to roadbed, curves, and grades. In addition, careful analysis should be made of the costs of various kinds of fuel or power.

Consideration of length of haul and gross load per trip involves study of the probable time cycle and therefore the speed required. It also involves study of the weight and tractive effort necessary to handle the required load.

Consideration of the resistance offered by the roadbed, curves, and grades also involves a study of speed and tractive effort, but the emphasis in this case is on the latter.

A locomotive capable of handling the calculated gross load per trip in the required time cycle over a level track might be entirely inadequate were it necessary to put in a slight adverse grade or a sharp curve.

As a general rule it is better to select a locomotive that will provide ample capacity under maximum adverse conditions. The cost of extra power over and above that needed for favorable conditions can easily be exceeded by that of delays due to inadequate power under adverse conditions. Just how much surplus power an operator is justified in providing is largely a matter of individual opinion and may range from 25 to 100 percent of normal requirements under favorable conditions. Ordinarily, however, if the maximum possible adverse conditions are calculated for each factor and the selection is made on this basis the unit should be satisfactory. Allowance for future increased production should be made by additional units rather than excess size at the start.

The selection of the type of power to be used also depends upon local conditions. Coal-fired steam locomotives have in the past proved most popular. However, advances made in the design and flexibility of the mechanical application of internal-combustion engines have caused many operators to show preference for the gasoline or Diesel locomotive.

Electric power so far has found little favor with sand and gravel producers.

Steam power is flexible and permits the slow movement necessary in starting and accelerating a load as well as higher speed when under way. Steam locomotives are capable of considerable overload when adverse conditions require excess power. However, they require periodic supplies of fuel and water, and usually, but not always, some working time is lost in supplying them.

Large steam locomotives require two men to operate them, an engineer and a fireman, either or both of whom may be required to pass certain State examinations for qualification. In smaller locomotives the engineer often does his own firing. Steam locomotives require time to warm them up and generate steam before they are ready to operate.

Gasoline or Diesel locomotives are usually designed to provide maximum power when operating at a certain engine speed. Flexibility in running speed has been provided by including two or more gear ratios at which the locomotive speed can be altered but keeping the engine speed the same. They are capable of an appreciable overload. They also require periodic supplies of fuel, but ordinarily they are supplied with fuel tanks sufficient to carry them through a working period. One man only is needed to operate them, and usually no State regulatory laws as to qualification apply. In cold weather gasoline or Diesel motors are sometimes hard to start, but this is usually eliminated by providing housing facilities for them when off duty.

In the larger sizes combination Diesel-electric locomotives have been demonstrating considerable economy in railway and switching operations according to some users. In this type a Diesel engine is used to drive an electric generator which furnishes power for the driving motors; all are on the same chassis. This combination, however, is usually applied to long hauls with standard equipment rather than to gravel-pit haulage.

The application of outside electric power to locomotives requires either an overhead trolley or a third rail to carry the current, or the locomotive must be equipped with a large storage battery.

Overhead-trolley and third rail systems have been frowned upon by sand and gravel operators for various reasons. Some dislike them because of the danger to workmen. Others object because of the cost of maintaining the bond between rails, the expense of carrying the trolley line along with the track, and the additional cost involved in shifting electrical apparatus along with the pit track. The principal objection to the storage-battery type has been its first cost and slow speed.

All these objections are founded on the experience of gravel-pit operators. However, producers of other materials have found both types of electric locomotives flexible and

economical. Manufacturers of the trolley or third-rail type have equipped their machines with automatic reels which carry two armored cables. By the use of these reels the trolley or third rail can be terminated at the end of permanent track. At this point the ends of the cables can be attached to the rail and trolley, and the locomotive can then proceed on power supplied from the cable. The reels are automatic in that as the locomotive is reversed they rewind the cable previously paid out. Cable length is limited in practice to about 1,000 feet.

Another arrangement is provided in which a wire rope is carried on a reel at the front of the locomotive. This can be stretched by hand to reach cars beyond the reach of the power line. By this means the locomotive can pull in such outlying loads.

The storage-battery locomotive requires considerable time for recharging. Suitable equipment for recharging must also be supplied. Once charged, however, it is just as mobile as either the steam- or oil-powered machine. If the battery charge is reduced to the danger point some types can be recharged through the trolley wire; others must be returned to a central charging station. If the battery charge is depleted below that necessary to handle the train it will usually still retain enough stored energy to return the locomotive, although the train may have to be abandoned.

The electric locomotive can be used for either low or high speeds and is capable of overloading for short periods.

It requires no fuel supply other than lubricants but must have power lines or facilities for battery charging. In some instances batteries are replaceable; as soon as one is depleted it is removed and placed on the charging rack and a freshly charged battery is placed on the locomotive chassis.

Electric locomotives are operated by one man, and no regulatory examinations are required.

In addition to these types of locomotives there are others less often used but worthy of mention.

The compressed-air locomotive is essentially an air receiver on a locomotive chassis. The receiver is charged with compressed air under high pressure and uses this expansively in suitable driving engines. Like the storage-battery type, it must be returned to a charging station for a fresh supply of power.

A somewhat similar type is the fireless steam locomotive. The receiver in this case is partly filled with water and is then charged with steam under high pressure at a charging station. The expanding steam is utilized in the same way as in a locomotive making its own steam. This type also must be returned to the charging station for a fresh supply of power.

Electric, compressed-air, and fireless steam locomotives are particularly advantageous for use underground or wherever the gases of combustion from coal- or oil-fired steam locomotives or the exhaust gases from gasoline or Diesel engines are detrimental to health.

Electric power through a third rail has been successfully applied to a method of operating single cars equipped with their own motive power and operating without an accompanying attendant. These systems have been designed to use direct or alternating current, and by suitable arrangements only a portion of the track is electrified at any one time. In operation the cars are controlled by one man stationed in a centrally located tower from which he can see all cars at all times. By means of a properly constructed control panel he can start, stop, or back a car at any point on its circuit. The system is expensive in first cost but is said to be low in operating cost. Fewer but more expensive cars are required, and users claim that the delay at the digger due to lack of empty cars is a minimum. The system is open to the same objection as that of the trolley locomotive where tracks must be shifted at frequent intervals. Where the pit affords a long circular or elliptical working face in which the track can parallel the route of the digger and the volume of material warrants the initial expense, these remote-control systems offer interesting possibilities.

Condition of Track

Gravel-pit track may be permanent or temporary, depending on the design of the haulage system. Where a long straight or slightly curved working face is available and the track parallels the path of the excavation unit, it pays to ballast the track and build it in accordance with at least semipermanent design. Where it is necessary to shift the track with each move of the excavator this is impossible, and the track must be temporary. Usually, at some distance from the excavator (varying with working conditions), the track can be made permanent and well-ballasted to and from the dump.

Occasionally the difference in elevation between working face and dump is too great for a single grade, and no space is available for spiral ascent. In such cases switch-backs may be employed, or the locomotive may be replaced or supplemented by a hoist operating on an inclined plane.

Track gage ranges from a minimum of 20 inches to a maximum of 4 feet 8 1/2 inches or standard railway gage. In general, no rule can be laid down as to the relation between track gage and car capacity or locomotive weight, although one manufacturer definitely limits cars of 6 cubic yards or over to standard gage. Ordinarily, however, 24-inch gage is the minimum used with locomotive haul. Judged by number of installations, 36- and 42-inch gages are most popular in the so-called narrow-gage field. Generally, the maximum weight for locomotives on 24-inch gage track is 8 to 10 tons and on 30 to 36 inch gage, 12 to 25 tons; over 25 tons requires standard gage. The same may be said to apply to the gross weight of cars.

Narrow-gage track is usually laid with lighter rails and therefore is more easily and quickly shifted. It can be purchased in standard lengths with steel ties attached, which facilitates relaying when frequent shifting is necessary. Locomotive speed is usually lower with narrow-gage track, and such track can therefore be laid with less care as to curvature and grades.

Standard gage permits railway equipment to be shunted to any part of the pit but requires heavier rails, easier curves, lower grades, and more initial expenditure if railway equipment is used. Standard gage permits larger locomotives and cars and consequent lower per-ton-mile haulage cost for labor power and repairs. It is not justified for pits with small tonnage outputs, although just where the line should be drawn between small and large tonnage depends upon local conditions.

On sharp curves the gage must be widened to reduce friction. For standard gage on curves of over 8° the gage should be widened 1/8 inch for each 2° of curve to a maximum of 4 feet 9 1/4 inches.

The proper ratio of rail weight to locomotive weight involves the distribution of the locomotive weight on each drive wheel and the spacing of the ties under the rail. Pit locomotives are usually of the 4- or 6-wheel drive type, and tie spacing usually averages 24 inches center to center. At some plants ties may be spaced as close as 18 inches, while at others they may be spaced 36 inches or more in portable track. Table 45 offers suggested safe combinations of tie spacing, weight of rail, and weight on locomotive drivers.

Sharp curves in the track should be avoided if possible because of the increased resistance to movement of equipment. In pit tracks, particularly those of a temporary nature, this is not always possible. Where necessary, curves should never be sharper than required by the length of the locomotive wheel base. Double-truck pit cars are usually so constructed that each truck has a limited rotative movement which permits the use of sharper curves than their total wheel base would require if rigid.

TABLE 45.- Relation between tie spacing and rail and locomotive weight

Locomotive weight, tons	4		6		8		10		13		15		20	
Number of drivers	4	6	4	6	4	6	4	6	4	6	4	6	4	6
Wheel load, pounds	2,000	1,333	3,000	2,000	4,000	2,667	5,000	3,333	6,500	4,333	7,500	5,000	10,000	6,667
Ties Spaced at 18 Inches														
Rail weight, pounds per yard	16	16	20	16	25	20	30	25	40	30	40	30	50	40
Ties Spaced at 24 Inches														
Rail weight, pounds per yard	20	16	25	20	30	25	40	30	50	40	50	40	55	50
Ties Spaced at 36 Inches														
Rail weight, pounds per yard	25	20	30	25	40	30	40	30	50	40	55	50	65	55

Curves laid out on permanent track should have the outer rail raised somewhat to facilitate the movement of cars. The amount of elevation depends upon the speed at which cars travel around the curve and the degree of the curve. A common rule for determining the elevation of the outer rail is 1 inch for each degree of curve for level track and, if the grade is over 2 percent, 3/4 inch for each degree of curve. This corresponds to a train speed of 38 miles per hour. Table 46 gives the elevations for lower speeds.

TABLE 46.- Elevation of outer rail, inches

Curve, °	Speed, miles per hour				
	15	20	25	30	35
1	1/8	1/4	3/8	5/8	7/8
2	1/4	1/2	7/8	1 1/4	1 3/4
3	1/2	7/8	1 1/4	1 7/8	2 1/2
4	5/8	1 1/8	1 3/4	2 1/2	3 3/8
5	3/4	1 3/8	2 1/8	3 1/8	4 1/4
6	7/8	1 5/8	2 5/8	3 3/4	5 1/8
7	1 1/8	1 7/8	3	4 3/8	5 7/8
8	1 1/4	2 1/4	3 1/2	5	6 3/4
9	1 3/8	2 1/2	3 7/8	5 5/8	7 5/8
10	1 1/2	2 3/4	4 1/4	6 1/4	8 1/2
11	1 3/4	3	4 3/4	6 7/8	....
12	1 7/8	3 1/4	5 1/8	7 1/2	....
13	2	3 5/8	5 5/8	8 1/8	....
14	2 1/8	3 7/8	6	8 3/4	....
15	2 3/8	4 1/8	6 1/2	9 1/4	....

The horsepower of the power unit on any locomotive can be calculated from its construction characteristics in the same way as that for a similar unit in any other service. This, however, is only an indirect measure of the power of the locomotive. The power unit uses its energy to revolve the drive wheels of the locomotive and through such revolution to move the locomotive and any load to which it is attached. In converting the revolving motion of the drive wheels to linear motion of the locomotive other factors are involved.

Let us assume that a locomotive is placed on the end of a track with its front end against an immovable block so that it cannot move forward. Now, if the power unit is started, the drive wheels cannot revolve until enough force is applied to overcome the adhesion between the tires and rails. If sufficient force is applied, the drivers will revolve or slip on the rails, but the locomotive cannot move.

Now assume the same locomotive is placed on a straight, level track without anything to prevent its movement, and sufficient grease or other lubricant is placed between the rails and drivers to prevent any adhesion. When power is applied through the power unit the drivers revolve, but again the locomotive does not move. In both cases the power unit functions, but the locomotive does not. In the first case the power applied was a maximum and in the second case a minimum.

It is evident that for the locomotive to function there must be adhesion between tire and rail and that the applied power cannot exceed that which the adhesion will support, as otherwise the wheels will slip. The adhesion between tire and rail depends upon the material of which the tire and rail are made, the weight on the tire, and the condition of the surfaces in contact. Locomotive wheels are made of cast iron or cast steel, and they may or may not have forged-steel tires. Rails are made of steel. The adhesion is greater between a steel tire and a steel rail than between a cast-iron tire and a steel rail. The adhesion between tire and rail varies directly with the weight on the tire.

Adhesion varies also with the condition of the surfaces in contact. Thus, a rail covered with dry snow, sleet, grease, or dew will present a variety of conditions all offering less adhesion than if the rail were clean and either thoroughly wet or dry. There is little difference in a thoroughly wet or dry rail if it is clean. In any of the cases cited, however, the application of sand to the rail will raise the adhesion.

The power of a locomotive is measured by the tractive effort of which it is capable. The tractive effort is calculated by multiplying the weight of the locomotive carried on the drive wheels by the coefficient of adhesion between tire and rail.

The coefficient of adhesion is the tractive force required to slip the drivers divided by the weight on the drivers.

The Baldwin Locomotive Works has determined the coefficient of adhesion for various conditions, as presented in table 47.

TABLE 47.- Approximate coefficient of adhesion

Condition of rails	Chilled cast-iron wheels		Steel-tired wheels	
	Wthout sand	With sand	Without sand	With sand
Covered with dry snow	0.10	0.15	0.10	0.15
Covered with sleet......	.15	.20	.15	.20
Greasy, moist..........	.15	.25	.15	.25
Outdoor moist..............	.18	.22	.18	.22
Thoroughly wet, clean	.20	.25	.25	.31
Dry, clean..................	.20	.30	.25	.37
Best conditions........	....	.38 to .42	....	.47 to .52

From the table it is seen that with dry rails the tractive effort of which a locomotive is capable will vary with cast-iron wheels from 20 to 25 percent of the weight on the drivers and with steel tires from 25 to 30 percent. Thus, a locomotive weighing 6 tons will be capable of a tractive effort of 2,400 to 3,600 pounds.

It will be noted that the tractive effort is calculated without reference to the horsepower of the power unit. Power units are usually designed to supply the maximum tractive effort with maximum adhesion at starting speeds.

Another unit used to measure locomotive power is the drawbar pull of which it is capable. This is always less than the tractive effort. The drawbar pull of a locomotive is that force which it is capable of supplying at its drawbar to pull a trailing load. It is the tractive effort minus the resistance to motion of the locomotive. The resistance of the locomotive is calculated in the same manner as train resistance in the preceding chapter, giving the same consideration to grade and curvature of track.

Tractive force as applied to locomotives is the force applied by the power unit to the rim of the drive wheels. If the power unit is capable of supplying enough force to overcome track adhesion and slip the drivers, the tractive force is greater than the tractive effort and vice versa.

The tractive force of a 2-cylinder single-expansion steam locomotive may be calculated from the following equation:

$$T = 4 \times \frac{\pi d^2 P S}{4 \pi D} = \frac{\pi d^2 P S}{D}$$

in which

T = tractive force, in pounds;
d = diameter of the cylinder, in inches;
P = mean effective pressure (85 percent of the boiler pressure);
S = length of stroke, in inches;
D = diameter of drive wheel, in inches.

Note that for each revolution of the drive wheel there are 4 pressure impulses from the 2 steam cylinders.

The indicated horsepower of a steam engine may be calculated from the following equation:

$$\text{I. hp.} = \frac{PLAN}{33{,}000},$$

in which

I.hp. = indicated horsepower for each cylinder;
P = mean effective pressure (85 percent of the boiler pressure);
L = length of stroke, in feet;
A = area of cylinder, in square inches, $\frac{\pi d^2}{4}$;
N = number of single strokes per minute.

The train speed must be known to determine N. This may be found from the following equation:

$$LN = \frac{M \times 88 \times 2S}{\pi D},$$

in which

LN = piston speed, in feet per minute;
M = train speed, in miles per hour;
S = stroke, in inches;
D = diameter of driver, in inches.

Substituting for LN, the equation for a 2-cylinder steam locomotive becomes:

$$I.Hp. = 2x \frac{Px \dfrac{\pi d^2}{4} x \dfrac{Mx88x2S}{\pi D}}{33,000}$$

$$= \frac{88\ Pd^2\ SM}{33,000\ D} = \frac{d^2\ PS}{D} x \frac{M}{375}$$

Since

$$\frac{d^2\ PS}{D} = T,$$

then

$$I.Hp. = \frac{TM}{375},$$

and

$$T = \frac{375\ I.Hp.}{M}.$$

The internal resistance of steam engines varies with the design, lubricaton, etc., and may range from 6 to 38 percent of the indicated horsepower. The brake horsepower for locomotives commonly used in sand and gravel haulage may be assumed at 75 percent of the indicated horsepower.

Therefore the formula for brake horsepower is

$$B.Hp. = \frac{3}{4} x \frac{TM}{375} = \frac{TM}{500},$$

and

$$T = \frac{500\ B.Hp.}{M}.$$

Gasoline Engines

The horsepower of gasoline engines is calculated from a number of different formulas originating with various technical authorities, no two of which agree exactly. The differences are probably due to different engine designs and variations in the efficiency with which the gasoline vapor is mixed and consumed.

Gasoline-engine horsepower can be calculated from the same equation as that for steam-engine horsepower if proper changes are made to account for the use of gasoline power.

The steam-engine equation was:

$$\text{I.Hp.} = \frac{PLAN}{33{,}000}$$

In a gasoline or oil-burning locomotive the engine speed can usually be varied between 500 and 1,000 r.p.m., and the locomotive speed can be varied by shifting the transmission gears which change the ratio of the r.p.m. of the motor to that of the drive axle. Therefore, an equation defining piston speed LN in terms of train speed must include the gear ratio between motor and drive axle and must take into consideration the range of motor speeds. Gear ratios on gasoline locomotives are not standardized but vary with different manufacturers. There is a loss of efficiency in transmitting power from the motor to the drive axle through the transmission gears. This varies with different designs but may be assumed at 20 percent for purposes of computation.

In the 4-cycle gasoline engine, which is the type commonly used for industrial locomotives, each piston makes 4 single strokes in 2 revolutions of the drive shaft, but only 1 of these is an explosion or effective stroke. Therefore, the effective strokes per revolution are one half the number of pistons working.

Let R equal the total ratio and C the number of pistons or cylinders.
Then

$$L\ N = \frac{M \times 88 \times \frac{C}{2} \times S \times R}{\pi\ D},$$

$$= \frac{\times\ 88 \times C \times S \times R}{2\ \pi\ D}.$$

Substituting this value for LN in the original steam-engine equation,

$$\text{I.hp.} = \frac{PA}{33{,}000} \times \frac{M \times 88 \times C \times S \times R}{2\ \pi\ D},$$

$$= \frac{d^2\ PCSR}{8\ D} \times \frac{M}{375}.$$

The equation for tractive force for a 2-cylinder, single-expansion steam engine was:

$$T = 4 \times \frac{\pi d^2\ PS}{4\ \pi\ D}.$$

As there were 2 cylinders, there were 4 effective strokes per revolution. The equation for the 4-cycle gasoline engine must again account for the ratio between motor and drive axle, the number of cylinders, and the effective strokes per revolution.

This equation then becomes:

$$T = \frac{C}{2} \times \frac{\pi d^2 PSR}{4 \pi D} = \frac{d^2 PCSR}{8 D}.$$

Substituting in the previous equation,

$$I.hp. = \frac{TM}{375},$$

and

$$T = \frac{375 \times I.hp.}{M}.$$

These are the same as the corresponding formulas for steam engines.

The efficiency of gasoline engines ranges from 75 to 85 percent, averaging 80 percent of the indicated horsepower, but as previously stated there is an average loss of 20 percent in the transmiss on gearing. Hence,

$$B.hp. = \frac{4}{5} \times \frac{4}{5} \times \frac{TM}{375} = \frac{TM}{588}, \text{ and } T = \frac{588 \text{ B.hp.}}{M}.$$

The horsepower of a 4-cycle gasoline motor may be computed from the steam formula as follows:

$$I.hp. = \frac{PA}{33,000} \times LN,$$

$$N = \frac{C}{2} \times r.p.m. \text{ and } L = \frac{S}{12},$$

$$S = \text{stroke in inches;}$$

substituting,

$$I.hp. = \frac{PA}{33,000} \times \frac{C}{2} \times r.p.m. \times \frac{S}{12},$$

$$= \frac{PACS}{792,000} \times r.p.m.$$

But AS = V = the volumetric displacement of each cylinder in cubic inches. Therefore,

$$I.hp. = \frac{PVC}{792,000} \times r.p.m.$$

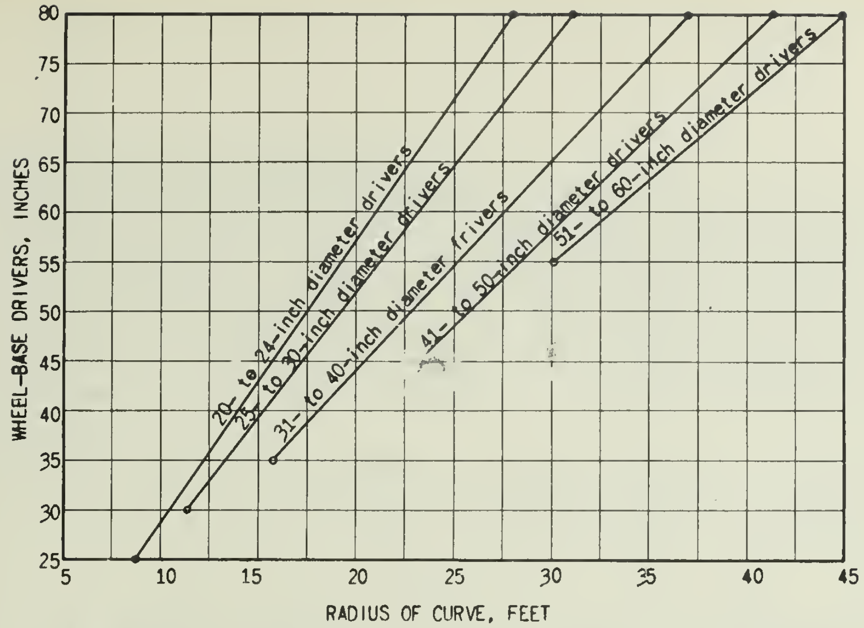

Figure 16.- Relation between diameter of drive wheels, length of wheel base (four-wheel rigid trucks), and radius of curve. Rigid trucks of six or more wheels can negotiate these curves if the center wheels have sufficient lateral clearance or have plain tires without flanges.

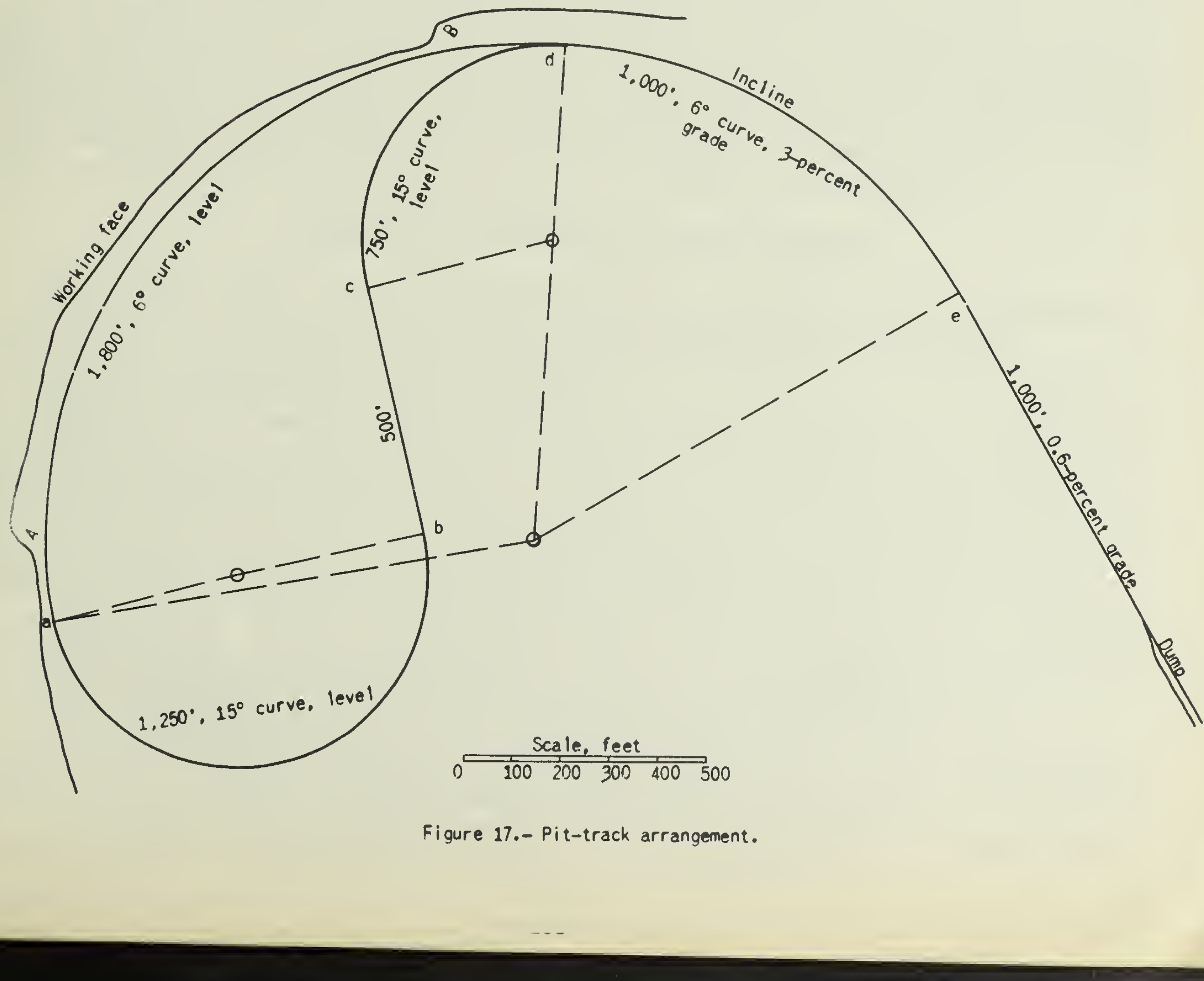

Figure 17.- Pit-track arrangement.

Brake horsepower will vary as before.

The value of P or the men effective pressure in gasoline engines will vary with the efficiency of combustion. The range in pounds per square inch will be from 65 to 85 with 75 to 80 commonly used in computation. This mean effective pressure as applied to gasoline engines is based on atmospheric pressure at sea level (29.92 inches of mercury) and a standard temperature of 60 F . Accurate computation of the horsepower of internal-combustion engines must take these factors into consideration. The power developed by an internal-combustion engine decreases at an average rate of about 3 percent for each 1,000-foot rise in elevation above sea level.

The diameter of the drivers and the length of the rigid wheel base determines the degree of curvature in the track which a locomotive can safely negotiate. Figure 16 shows the approximate relation between these three items. The curve radius is the minimum that should be used.

Pit haulage with locomotive power is limited by the increased tractive force required for each degree rise in grade to a maximum of 6 percent except for short distances. In fact, customarily grades are kept below 4 percent.

It may be pertinent here to mention one type of locomotive which may be used on steeper grades but which has been used comparatively little in gravel-pit operation. This machine has a pinion on the axle between its drive wheels. On steep grades a rack is laid between the rails and fastened to the ties. As the locomotive approaches the grade its pinion engages the teeth on the rack, obviating the necessity for adhesion between tire and rail. This type of locomotive can negotiate grades up to 10 or even 15 percent.

Occasionally locomotives are required to descend heavy grades with loads and return empties up grade. If there is no sharp curve at the foot of the grade no greater locomotive weight may be required. If there is a sharp curve at the foot of the grade and speed down grade must be decelerated, it may be necessary to install a heavier locomotive than would be required to return the empties up grade. If the cars are not equipped with brakes and the entire deceleration must depend on the locomotive brakes, the locomotive should be of such weight as to provide 20- to 25-percent adhesion on the maximum descending grade.

CAPACITY OF LOCOMOTIVE- AND CAR-HAULAGE SYSTEMS

As previously stated, the capacities of locomotive- and car-haulage systems cannot be tabulated because of the many and divergent factors involved in local conditions.

Methods of calculating requirements are perhaps best illustrated by citing a hypothetcal example and making calculations accordingly.

Example 9. It is assumed that a gravel operator has just purchased a dry pit and laid out a haulage route, as shown in figure 17. The deposit has a working face averaging 30 feet in height and extending 1,800 feet from a to d (fig. 17). Entrance to the pit is down a 3-percent grade on a 6° curve for a distance of 1,000 feet (e to d). From the top of the grade (e) to the dump the track is 1,000 feet long and straight but has an adverse grade of 0.6 percent. Pit tracks are level and in accordance with the curves, as shown in figure 17.

There are two 1 1/2-cubic yard shovels located at A and B, each 250 feet from the ends of the working face. A switch is provided at the foot of the 3-percent grade (d, fig. 17).

Running clockwise, the haulage length from shovel A will be 3,550 feet and the return 4,750 feet. From shovel B the haul will be 2,250 feet and the return 6,050 feet.

From the track lay-out, all but that paralleling the working face can be laid as permanent track. Therefore, standard gage is selected. However, very little of the track is straight, hence long trains should be avoided because of curve resistance.

It is assumed that the gravel is loose and free from large boulders or clay and that a minimum production of 300 tons hourly is required for an 8-hour day.

Reference to part I, table 9, in the chapter on power shovels shows that the two 1 1/2-cubic yard shovels will have an hourly capacity ranging from 280 to 530 tons. Under average working conditions these two machines should produce the required tonnage in 6 hours, or they will have an excess capacity of 33 1/3 percent. Moreover, if one shovel is incapacitated for any cause the other can produce the required tonnage by working a short overtime stretch.

Working continuously, each shovel will dig and load an average of 200 tons per hour or 3 1/3 tons per minute, which is the equivalent of 1.48 full dipperloads per minute. The effect of partly loaded dippers was considered in computing shovel capacity, hence need not be considered here.

The shovels, it is assumed, can cut a path 40 feet wide from the bank, which in 1,800 feet of working face will supply upwards of 150,000 tons of gravel, or more than 60 days operation for each cut. The track at the working face, therefore, need not be moved frequently. However, since no loading switches are used at the shovels each train must be partly loaded by each shovel. If 2 trains are used each shovel will necessarily be idle while trains are in transit. With 3 trains, shovels may be kept constantly supplied with cars; but since each train must pass twice over the switch at the foot of the 3-percent grade on each trip, there will be six crossings in each complete haulage cycle. This may or may not be serious.

For efficient operation each car should hold at least three full dipperloads. Since both shovels swing 1 1/2-cubic yard dippers, the minimum car size is established at 4 1/2 cubic yards. However, it has already been decided that standard-gage track will be used. Car builders' catalogs list 6 cubic yards as the minimum-size standard car for standard-gage track. Therefore, the minimum car is selected, holding 6 cubic yards or 9 tons of payload per car. The maximum size probably would not exceed 30 cubic yards or 45 tons.

The shovel capacity which the haulage unit must serve is 400 tons per hour or 1 ton every 9 seconds.

In computing the time per haulage cycle, efficiency requires that the loading time - time the cars are at the shovels - should equal transit and dumping time - time the cars are away from the shovels.

The track arrangement in figure 17 shows a total round-trip distance of 8,300 feet, which at an average train speed of 10 miles per hour would require 9 minutes and 26 seconds.

Since the loading, dumping, and transit time for any train varies with the number of cars in the train, the train size must be assumed before a train time schedule can be computed. This necessitates a cut-and-try method of initial calculation.

Assuming that the unit adequately serves the shovels, that the dumping time is 30 seconds per car irrespective of size, and that the transit time is 10 minutes per train, also irrespective of size, the time cycles for various train units is as shown in table 48.

From table 48, a train of twelve 6-cubic yard or 9-ton cars will require 972 seconds to load at each shovel, assuming 6 cars are loaded at each shovel and that transit and dumping time is 960 seconds. The transit plus dumping time is slightly less than the loading time at each shovel, assuring constant shovel operation.

From the same table, the 30-cubic yard or 45-ton car will be used in 2-car trains, the 12-cubic yard or 18-ton car in 5-car trains, and the 20-cubic yard or 30-ton car in 3-car trains.

Since each shovel dipper carries 2.25 tons the 9-ton car will require 4 dipperloads, the 18-ton car 8 dipperloads, and the 45-ton car 20 dipperloads. The 30-ton car, however, will require 14 loads and consequently will carry 31.5 tons. Obviously the selection of the car size is not limited to those sizes cited. The four sizes, however, show how train units may be balanced. In the following computations only the 6-cubic yard car, assumed to weigh 6 tons empty, and the 30-cubic yard car, assumed to weigh 40 tons empty, are used.

TABLE 48.- Train-time cycles (seconds)

Payload in car, tons	Number of cars in train	Payload in train, tons	Loading time at each shovel	Transit time	Dumping time	Total cycle time
9	5	45	405	600	150	1,560
9	10	90	810	600	300	2,520
9	11	99	891	600	330	2,712
9	12	108	972	600	360	2,904
9	13	117	1,053	600	390	3,096
45	1	45	405	600	30	1,440
45	2	90	810	600	60	2,280
45	3	135	1,215	600	90	3,120
18	4	72	648	600	120	2,016
18	5	90	810	600	150	2,370
30	3	90	810	600	90	2,310

Table 48 shows that the train of twelve 9-ton cars delivers a payload of 108 tons in a time cycle of 2,904 seconds. The haulage duty required to serve the shovels is 2,400 tons in 6 hours or 21,600 seconds. There will then be $\frac{2,400}{108}$ = 22.22 train loads required in 6 hours.

A single train can make $\frac{21,600}{2,904}$ = 7.44 round trips in 6 hours.

Therefore, $\frac{22.22}{7.44}$ = 3 trains required.

Similarly,

$\frac{2,400}{90}$ = 26.67 trainloads required of 30-cubic yard cars.

$\frac{21,600}{2,20}$ = 9.5 round trips in 6 hours.

$\frac{26.7}{9.5}$ = 2.8 or 3 trains required.

With a combination of 2 shovels and 3 trains the loading time at each shovel must approximate the transit plus dumping time for greatest efficiency in the haulage unit.

With good cars well-maintained and the conditions specified as to curves and roadbed, the rolling resistance probably would not be over 30 pounds per ton of gross train weight with the 6-cubic yard cars and 20 pounds with the 30-cubic yard cars.

The 3-percent grade on a 6° curve will present the maximum tractive-effort requirements, and locomotive weight will be computed on this basis.

The gross trailing load for the 12 small cars will then be 12 x 15 = 180 tons and for the 4 large cars, 2 x 85 = 170 tons.

The required locomotive weight for gravel-pit haulage can be found from the following formula:

$$20\ WK = FA + FW + 20\ GA + 20\ GW + CA + CW.$$

in which

W = weight of the locomotive, in tons;
A = weight of the trailing load, in tons;
G = grade, in percent;
F = running resistance, in pounds per ton;
C = curvature of the track, in degrees;
K = the coefficient of adhesion, in percent.

Assuming that the locomotives will be equipped with steel-tired drivers and thus permit using a coefficient of friction of 25 percent, and substituting in the formula the conditions applicable to the 3-percent grade:

For 6-yard cars -

$$20W \times 25 = (30 \times 180) + 30W + (20 \times 3 \times 180) + (20 \times 3 \times W) + (6 \times 180) + 6W$$

$$500W - 96W = 17{,}280$$
$$W = 42.8 \text{ tons.}$$

For 30-yard cars -

$$20W \times 25 = (20 \times 170) + 20W + (20 \times 3 \times 170) + (20 \times 3 \times W) + (6 \times 170) + 6W$$

$$500W - 86W = 14{,}620$$
$$W = 35.3 \text{ tons.}$$

These locomotive weights may be checked by the following computation of train resistance.

			6-cubic yard cars	30-cubic yard cars
Gross train weight =	180 + 42.8	=	222.8 tons	
	170 + 35.3	=		205.3 tons
Rolling resistance =	222.8 x 30	=	6,684 pounds	
	205.3 x 20	=		4,106 pounds
Grade resistance =	222.8 x 20 x 3	=	13,368 pounds	
	205.3 x 20 x 3	=		12,318 pounds
Curve resistance =	222.8 x 6 x 1	=	1,369 pounds	
	205.3 x 6 x 1	=		1,232 pounds
Total resistance =			21,421 pounds	17,656 pounds

At 25-percent adhesion the locomotive weight must be 4 times the total resistance, or

$$4 \times 21{,}421 = 85{,}684 \text{ pounds} = 42.8 \text{ tons.}$$
$$4 \times 17{,}656 = 70{,}624 \text{ pounds} = 35.3 \text{ tons.}$$

Selection of locomotives at those weights would require the maximum duty of which they were capable on the 3-percent grade. Since no machine works efficiently if operated continuously at its maximum capacity, the actual selection should be locomotives of greater than the calculated weight. In regular work the locomotive should be used at not more than 75 percent of its tabulated tractive effort.

Therefore the maximum tractive effort of which the chosen locomotives should be capable is:

$$\frac{21,421}{0.75} = 28,560 \text{ pounds, and}$$

$$\frac{17,656}{0.75} = 23,540 \text{ pounds.}$$

At 25-percent adhesion they should weigh 57 and 47 tons, respectively.

In steam locomotives the tractive force is calculated from the following formula:

$$T = \frac{d^2\ p\ S}{D},$$

in which

T = tractive force, in pounds;
d = diameter of the cylinder, in inches;
p = mean effective pressure (this is usually taken as 85 percent of the boiler pressure);
S = stroke, in inches;
D = diameter of the driver, in inches.

Thus, a locomotive having a 19-inch cylinder by 24-inch stroke, with a 46-inch driver, will develop a tractive force of 28,800 pounds at 180 pounds boiler pressure, and a 57-ton locomotive is capable at 25-percent adhesion of 28,500 pounds tractive effort.

Moreover, a locomotive having a 17-inch cylinder by 24-inch stroke with a 44-inch driver will develop a tractive force of 24,100 pounds at 180 pounds boiler pressure, and a 47-ton locomotive is capable at 25-percent adhesion of 23,500 pounds tractive effort.

The probable weights chosen from commercial sizes would be 60- and 50-ton locomotives. Having determined the size of the locomotive, the next step in calculating the haulage capacity of the system is computation of the time cycles.

Computation of time cycles involves calculation of the safe speed at which the trains may move. This is limited by the grade, curvature, and condition of the track. It may also be limited to a specific maximum by governing the locomotive.

The safe speed on curves in miles per hour equals the square root of the radius of the curve in feet. The radius of a 1° curve is 5,730.65 feet, and the radius of any curve is 5,730.65 divided by the number of degrees.

The safe speed on grades depends on the weight of the locomotive and train and the condition of the track.

Since the sharpest curve in figure 17 is 15°, the safe speed will be:

$$\frac{5,730}{15} = 19.54 \text{ miles per hour.}$$

Assuming the trains in either case will be run in a clockwise direction,[4] the haulage route can be segregated into 10 sections, as follows (fig. 17):

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4 It is often desirable to reverse the position or direction of locomotives periodically in such service to avoid excessive flange wear on one side and distortion of springs and other parts.

Section	Length, feet	Grade, percent	Curve	Speed limit, m.p.h.
B – d.....	250	0	6°	....
d – e......	1,000	+ 3.0	6°	....
e – dump	1,000	+ 0.6	0	....
dump – e	1,000	– 0.6	0	....
e – d......	1,000	– 3.0	6°	....
d – c......	750	0	15°	19
c – b......	500	0	0	....
b – a......	1,250	0	15°	19
a – A......	250	0	6°	....
A – B......	1,300	0	6°	....

Assuming a maximum speed of 20 miles per hour and starting with a loaded train at shovel B, the tractive effort and time required for each section are as shown in table 49.

TABLE 49.– Tractive effort and time required

Section	6-cubic yard cars			30-cubic yard cars		
	Gross train weight, tons	Tractive effort, pounds	Time, seconds	Gross train weight, tons	Tractive effort, pounds	Time, seconds
B – d..............	240	15,360	34	220	11,880	34
d – e..............	....	23,040	69	....	18,930	69
e – dump........	....	10,080	86	....	7,040	86
Dumping[1].......	....	....	360	....	....	60
Dump – e........	132	7,590	64	130	6,180	64
e – d..............	....	–3,170	41	....	–4,420	41
d – c..............	....	5,940	27	....	4,550	27
c – b..............	....	3,960	18	....	2,600	18
b – A..............	....	5,940	67	....	4,550	67
A loadng[2]......	....	....	972	....	....	810
A – B..............	186	11,900	123	175	9,450	123
B loading......	....	....	972	....	....	810
Total time	....	....	2,833	....	....	2,209

[1]Dumping time assumed at 30 seconds per car.
[2]Loading time calculated at shovel capacity or 3 1/3 tons per minute or 162 seconds for each 6-cubic yard car and 810 seconds for each 30-cubic yard car. It is assumed that cars are spotted during the swing cycle of the shovel without loss of time.

An illustration of the method of computing figures in table 49 follows:

Section B – d

From table 42 resistance due to acceleration to 10 miles per hour in 250 feet is 28 pounds per ton, and the time required is 34 seconds.

Resistance due to curve is 1 pound per degree of curve, or 6 pounds.
Track resistance is 30 pounds for small and 20 pounds for large cars.
Total resistance is 28 + 6 + 30 = 64 pounds for small cars, and
28 + 6 + 20 = 54 pounds for large cars.

240 x 64 = 15,360 pounds, and
220 x 54 = 11,880 pounds.

Section d - e

	Small cars	Large cars
Rolling resistance.........pounds	30	20
Grade resistance............. do.	20 x 3 = 60	60
Curve resistance............. do.	6 x 1 = 6	6
Total resistance.......... do.	96	86

96 x 240 = 23,040 pounds, and
86 x 220 = 18,930 pounds.

Since the effort required is within the power of the locomotive, a constant speed of 10 miles per hour is assumed. This is at the rate of 14.6 feet per second.

$$\frac{1,000}{14.6} = 69 \text{ seconds.}$$

In section e to dump, it is assumed that the speed of 10 miles per hour is continued for 750 feet, requiring 52 seconds, and deceleration takes place in 250 feet or 34 seconds.

In section dump to e, it is assumed that acceleration to 15 miles per hour requires 400 feet and, from table 42, takes 36 seconds. Six hundred feet at 15 miles per hour requires 28 seconds.

In section e - d, the 3-percent grade provides accelerative force over and above the resistance due to rolling friction and curve. The 15° curve at d limits speed to 19 miles per hour; hence the train will have to descend the grade on the brake. An average of 17 miles per hour is assumed for the section.

In sections d - c, c - b, b - a, and a - A, a speed of 19 miles per hour is assumed but decelerated in the last 400 feet.

In section A - B, acceleration to 10 miles per hour is assumed in 250 feet and 34 seconds. Deceleration is computed in the same distance and time at B. The balance of 800 feet is covered at 10 miles per hour.

The dumping time will, of course, depend upon the dumping facilities, but a half minute per car seems reasonable.

Loading time is the shovel loading rate. It is assumed that 6 small cars or 1 large car will be loaded at A and B.

From the time intervals of table 49, a train time sheet may be compiled, as in table 50. Train A starts to load at shovel B at 0 minutes, 0 seconds.

It is evident from a study of the train-time sheet that with three trains of small or large cars:

1. There will be 5- or 6-minute intervals between crossings at switch d.
2. There need be no delay of shovel equipment.
3. Using the small cars there will be a delay of 1 minute 23 seconds for each train, and using the large cars each train will be delayed 3 minutes 41 seconds. Therefore, the complete cycle with small cars will be 48 minutes 36 seconds and for the large cars 40 minutes 30 seconds.

TABLE 50.- Train time sheet

Station	6-cubic yard cars									30-cubic yard cars								
	Train A			Train B			Train C			Train A			Train B			Train C		
	H.	m.	s.	H	m.	s.	H.	m.	s.	H.	m.	s.	H.	m.	s.	H.	m.	s.
Ar. B	0	0	0	0	16	12	0	32	24	0	0	0		13	30		27	0
Lv. B	0	16	12	0	32	24	0	48	36		13	30		27	0		40	30
Ar. d	0	16	46	0	32	58	0	49	10		14	4		27	34		41	4
Ar. dump	0	19	21	0	35	33	0	51	45		16	39		30	9		43	39
Lv. dump	0	25	21	0	41	33	0	57	45		17	39		31	9		44	39
Ar. d	0	27	6	0	43	18	0	59	30		19	24		32	54		46	24
Ar. A	0	28	58	0	45	10	1	1	22		21	16		34	46		48	16
Lv. A	0	45	10	1	1	22	1	17	34		34	46		48	16	1	1	46
Ar. B[1]	0	48	36	1	4	48	1	21	0		40	30		54	0	1	7	30
Lv. B	1	4	48	1	21	0	1	37	12		54	0	1	7	30	1	21	0
Ar. d	1	5	22	1	21	34	1	37	46		54	34	1	8	4	1	21	34
Ar. dump	1	7	57	1	24	9	1	40	21		57	9	1	10	39	1	24	9
Lv. dump	1	13	57	1	30	9	1	46	21		58	9	1	11	39	1	25	9
Ar. d	1	15	42	1	31	54	1	48	3		59	54	1	13	24	1	26	54
Ar. A	1	17	34	1	33	46	1	49	58	1	1	46	1	15	16	1	28	46
Lv. A	1	33	46	1	49	58	2	6	10	1	15	16	1	28	46	1	42	16
Ar. B[1]	1	37	12	1	53	24	2	9	36	1	21	0	1	34	30	1	48	0

[1]All 6-cubic yard car trains wait 1 min. 23 sec. at shovel B and all 30-cubic yard car trains wait 3 min. 41 sec.

4. Three trains of twelve 6-cubic yard cars will deliver 2,376 tons to the dump in 6 hours, and three trains of two 30-cubic yard cars will deliver 2,430 tons in 6 hours.
5. Shovel-capacity service is assured.
6. Plant-capacity requirements are bettered by 30 percent.

HOIST AND ROPE HAULAGE

Hoists, like locomotives, do not in themselves generate power; both depend upon motors or other prime movers. The function of both is to translate the power of the prime mover into motion of the car or train. The locomotive converts that power into locomotive motion and transmits it to the car or train. The hoist remains stationary and converts power to motion by winding a wire rope on its drum.

Hoists may be employed for various haulage units among which are: (1) The engine plane, (2) the gravity plane, (3) the tail-rope system, and (4) the endless-rope system.

Engine Plane

A simple engine place consists of a single track on a plane or incline over which a load is raised or lowered by means of a single wire rope and hoist. The hoist is placed at the top of the incline and may be used to pull either loaded cars or empties up the incline. Motion down the incline is caused by gravity and is controlled by the hoist brake.

A double track may be used on an engine plane, but in such instances two ropes are used. Both may be attached to the same hoist drum, or each may be wound on a separate drum. The hoist pulls loaded cars up one track while the empties descend on the other. With two

ropes on separate drums the drums are usually locked in balance so that the descending empty cars assist in pulling up the loads.

The simple engine plane requires a single track only. The double-rope plane may use a single track for all but a short distance at the half-way point where switches allow the ascending and descending cars to pass, a three-rail track with passing switches half-way, or a double track throughout the whole incline.

With the engine plane, power is used for movement of cars in one direction and they are moved by gravity in the other direction.

Gravity Plane

The gravity plane is essentially a double-track engine plane in which loaded cars descend the incline and gravity is the only motive power. The hoist in this instance is used merely as a brake mechanism and in fact may have no power attachment. Descending loaded cars develop enough power to pull up the empties.

Tail-Rope System

In general, a tail-rope system operates the same way as an engine plane worked in both directions with two ropes. One rope called the "main rope" hauls the loaded cars in one direction, and the other or "tail rope" hauls the empties in the opposite direction. Tail-rope systems may be operated by two hoists, one placed at either end of the haulage route, or they may be worked with a double-drum hoist at one end. In the first instance, the hoist at the dump winds in the main rope and pulls out the tail rope from the other hoist. Both ropes are the same length. In the second instance, the main rope is wound on one drum and the tail rope on the other. The main rope is only as long as the haulage route. The tail rope, however, is twice the length of the haulage route, since it must pass from the hoist drum to a tail sheave at the extreme end of the haulage route and back to the hoist.

Tail-rope systems, like engine or gravity planes, may be used on steep inclines, or they may be used on slight grades or level tracks, since gravity is unnecessary as the motive power in either direction.

Endless-Rope System

As its name implies, the rope used in this system is endless. The rope is moved by a single wheel or drum, and friction is obtained either by a grip wheel or by two or more laps around the wheel. The rope is kept taut by means of tension blocks. In operation the rope travels in one direction at all times, and cars are attached to it by means of friction grips. The cars are attached or detached without stopping rope or hoist.

Endless-rope haulage systems can be used on inclined or level tracks.

Any type of rope haulage may be used to supplement other haulage units. For example, loaded cars may be collected at the excavator and hauled by locomotives to the foot or top of the plane or incline and there attached to the hoist rope.

Under favorable conditions all but the gravity plane may entirely supersede other haulage units. For example, when a single straight track will serve the excavator, enough momentum may be built up by empty cars in descending the incline to carry them over a considerable length of level track to the excavator.

Both tail-rope and endless-rope haulage systems may be operated around curves, over undulating track, and on branches from the main haulage route. Neither has found as favorable reception in American practice as locomotives, but both have been highly developed in European coal-mine practice.

Structural Limitations

The simple engine plane can be used only on grades that impart enough velocity to the descending unit to overcome the resistance of car or train plus the frictional resistance of the dragging rope. As they have only a single track, their service is intermittent in that the loaded car or train must be hauled to the dump and returned before a second load can be attached. They can be used to serve several excavation points over various tracks branching from the foot of the incline, if the momentum is sufficient to carry the descending cars to the excavator. In such instances, the haulage rope is cut in several pieces, one for each excavation point. As an empty car or train is delivered to one excavation point, the rope is left attached to the car or train but is disconnected at the foot of the incline. A rope from another point is then attached to that on the incline, and loads are hauled from that point. Service is thus intermittent from each digging point, although it may be continuous from the pit as a whole. This intermittent service is not suitable for use with mechanical excavators but may be advantageous for hand loading when the time required to load car or train equals the haulage cycle from another loading point in the pit.

When the engine plane is used to supplement other haulage units its intermittent operation is of less consequence, since the supplemented unit supplies continuous service to the excavators.

The engine plane may haul the pit cars singly or in trains as delivered to it, or it may use only 1 or 2 cars of different design into which the pit cars may be dumped.

Engine planes are seldom used except to haul loads up grades too steep for locomotives. They may be used on any grade from, say, 6 percent to a little less than vertical. On grades of over 45°, however, they usually require especially designed cars or skips to prevent spillage.

While single-track, simple engine planes are sometimes employed, they are usually limited to small production. Ordinarily, the double-track plane is used with balanced hoisting.

The gravity plane requires grades too severe for locomotive haulage and is used with double-track balanced movement only to lower loaded cars or trains down grade. If a simple brake wheel is used, no power is available to hoist cars or supplies to the working face other than that furnished by the descending loads. If a hoist is used power can be applied independently of the descending loads when necessary. Whatever the device, it must be located at the top of the incline and cannot follow the excavator. Therefore, gravity planes are limited to use in supplementing some other type of haulage unit serving the excavator.

Gravity planes may lower pit cars singly or in trains, or they may use especially designed cars as does the engine plane. They can be used for any grade in which the pull of the descending load is enough to overcome the friction of both descending and ascending cars, the frictional resistance of both trailing ropes, and the grade resistance of the ascending empty cars.

Like the engine plane its service is intermittent, but since it is used only to supplement other units this may be of minor importance. Under proper conditions, however, the use of a gravity plane effectually reduces haulage costs, since no power input is required. It can be used on the same range of grades as the engine plane.

Tail-rope and endless-rope haulage systems are seldom used in gravel pits. While they may be used on level or undulating tracks and around curves, they are usually limited to grades of less than 45°.

Service Equipment Required

Any haulage system using a hoist for motive power requires a rope as the connecting link between hoist and car or train. Ropes for haulage systems are composed of wires wound into strands, the strands then being wound into the finished rope. Wire rope may be purchased in various combinations in which the number of wires in the strands and the number of strands in the rope both vary.

Standard "hoisting" rope is composed of 6 strands, each having 19 wires. This type of rope is built primarily for vertical hoisting in which the rope does not drag. However, they are commonly used in engine-plane duty.

Standard "haulage" rope is composed of 6 strands, but each strand has only 7 wires. This type of rope is built for engine-plane and inclined-shaft hoisting in which the rope is subject to abrasion from dragging.

Standard hoisting rope is more flexible and somewhat stronger than standard haulage rope of equal diameter. Both types are made with either hemp or wire-rope centers. The former are more flexible and are more commonly used.

Haulage rope requires sheaves and hoist drums of larger diameter than hoisting rope. Sheave and drum diameters recommended are as follows:

	Minimum	Average
For 6 x 7 haulage ropes multiply rope diameter by....	42	72
For 6 x 19 hoisting ropes multiply rope diameter by	30	45

Both hoisting and haulage ropes may be obtained in which the wires are made of various grades of material ranging from low to high tensile strength as follows: Cast steel, plow steel, and improved plow steel. Plow steel is more commonly used for haulage ropes.

Haulage ropes may also be purchased in which the method of winding wires and strands varies. In "regular-lay" rope the wires in the strands are wound in one direction and the strands in the opposite direction. Thus a rope in which the wires are wound to the left and the strands to the right is known as a "right-lay" rope and one in which the wires wind to the right and the strands to the left as a "left-lay" rope. Both are regular lay. Ropes are also made with both wires and strands winding in the same direction. Those are known as "lang"-lay ropes. Lang-lay rope is somewhat more flexible than regular lay, and since the wires are exposed at the surface of the rope in longer lengths it will stand greater wear or abrasion and is therefore more suitable for haulage ropes that drag on the ground or over rollers. It untwists more readily than regular lay, however, and is apt to kink when tension is removed. For this reason it is not as easy to handle in coupling cars. Table 51 presents the principal characteristics of standard hoisting ropes and table 52 those for standard haulage ropes.

For haulage purposes the breaking strength of the rope should be 5 to 7 times the stress at which it is used. The safety factor of 5 should be used for steep inclines and that of 7 for low grades where the rope drags heavily.

The single- or double-rope engine plane ordinarily serves some other type of haulage unit and seldom requires service equipment other than the ropes. The hoist is stationary and requires fuel service, and this will depend upon the type of power used. In installations in which the plane hoists pit cars, no auxiliary service equipment is required. Planes employing especially designed cars or skips, into which pit cars are dumped, require some sort of apparatus for receiving the load from the pit car and transferring it to the car on the incline. Both types may require hoppers into which the loads are dumped at the top of the incline.

TABLE 51.- Characteristics of standard hoisting rope; 6 strands, 19 wires, hemp center

Diameter of rope, inches	Approximate weight per foot, pounds	Recommended diameter of sheave, feet	Approximate breaking strength, tons of 2,000 pounds		
			Cast steel	Plow steel	Improved, plow steel
3/8	0.23	1.5	4.5	5.5	6.3
1/2	.40	2.0	7.7	9.4	10.8
5/8	.63	2.5	11.8	14.4	16.6
3/4	.90	3.0	16.8	20.6	23.7
7/8	1.23	3.5	22.8	28.0	32.2
1	1.60	4.0	29.5	36.5	42.0
1 1/8	2.03	4.5	37.0	46.0	53.0
1 1/4	2.50	5.0	46.0	56.5	65.0
1 3/8	3.03	5.5	55.0	68.0	78.5
1 1/2	3.60	6.0	65.0	80.5	92.5
1 5/8	4.23	6.5	76.0	94.0	108.0
1 3/4	4.90	7.0	88.0	108.0	124.0
1 7/8	5.63	8.0	100.0	123.0	142.0
2	6.40	8.0	114.0	140.0	161.0

TABLE 52.- Characteristics of standard haulage ropes; 6 strands, 7 wires, hemp center

Diameter of rope, inches	Approximate weight per foot, pounds	Recommended diameter of sheave, feet	Approximate breaking strength, tons of 2,000 pounds		
			Cast steel	Plow steel	Improved, plow steel
3/8	0.21	2.25	4.3	5.15	5.9
1/2	.38	3.0	7.5	9.0	10.3
5/8	.59	4.0	11.5	13.8	16.0
3/4	.84	4.5	16.5	19.8	22.8
7/8	1.15	5.5	22.4	26.8	30.8
1	1.50	6.0	29.0	34.8	40.0
1 1/8	1.90	7.0	36.4	43.6	50.0
1 1/4	2.34	7.5	44.5	53.0	61.0
1 3/8	2.84	8.5	53.5	63.5	73.5
1 1/2	3.38	9.0	62.5	75.0	86.5

Where special incline cars are used the lower end of the incline track is frequently sunk below the pit floor. Pit cars are then run on trestles or bridges over, and dumped directly into, the incline car. In more elaborate systems, the pit cars pass over a wood, steel, or concrete hopper or bin. Delivery from bin or hopper may be directly through chutes controlled by gates or over feeder conveyors.

Capacity

There is no standardization of hoists and rope-haulage units. Hoists for such purposes are obtainable in almost any size and type using any kind of power and for any haulage duty. The hoists themselves are standardized by different manufacturers, and more or less uniformity exists between those standards. By this it is meant that manufacturers standardize their equipment by horsepower rating or the pounds of pull or speed the hoist can impart to the rope, although the design of the machine itself will vary with each factory, and in fact a single factory may produce various designs of equal power rating, rope pull, or speed.

Horsepower rating does not apply directly to the hoist itself but refers to the power unit used to drive the hoist. Custom, however, has made it common practice to refer to a hoist as of a certain horsepower. Strictly interpreted, this means that the particular hoist was designed to utilize the power developed by a motor or engine of the designated horsepower.

Rating by rope pull or speed refers directly to the hoist itself in translating the power of its prime mover into motion. Both the rope pull and speed of the hoist depend, however, upon the power and speed of the prime mover and the connecting arrangement between motor and hoist. Hence, all three ratings should be known to get a complete picture of the duty characteristics of any hoist.

Ordinarily the speed of the driving engine or motor, as expressed in revolutions per minute, is greater than that required in the hoist drum, and some method of speed reduction must be introduced. This may be done by different pulley diameters with belt or rope drive or by different tooth ratios with chain or gear drive. Sometimes reduction is only partly accomplished by this means, and further reduction occurs in the mechanism of the hoist itself.

In some instances, the revolutions per minute of the motive power and hoist drum are the same, and they are mounted on the same shaft or connected through rigid or flexible couplings.

The selection of a hoist for any type of rope haulage system requires information as to the rope pull and speed of which it is capable and the horsepower and speed required in the motor or engine to produce that rope pull and speed.

The rope pull required of a hoist for engine-plane duty will depend upon the grade of the plane, the gross or net weight and resistance of car or train (single or balanced hoisting), the frictional resistance of the dragging rope or ropes, and the speed of acceleration required.

The rope speed required for a similar duty will depend upon the length of haul or inclined length of plane and the relation between the payload capacity of the car or train and the time cycle permissible.

The horsepower necessary in the driving unit to produce the required rope pull and speed will depend upon the rope pull at the hoist drum, the efficiency of power transmission between drive unit and hoist, and to some extent on the type of power used.

Obviously the multiplicity of requirements due to variation in these factors prevents any tabulation of the capacities of hoist and rope-haulage units. While it is true that engine planes are seldom used, nevertheless where they are necessary it is important that they have adequate capacity when installed; therefore, a method of calculation is presented as follows:

Figure 18 represents an inclined plane of any grade on which rests a body indicated by the circle. The weight of this body due to the force of gravity acts vertically downward in the direction of the arrow pointing to W. However, since it rests on the plane, it cannot move in that direction. This force can be resolved into its two components, one acting parallel to the plane in the direction of A and one acting perpendicular to the plane in the

direction B. The former causes motion down the plane and the latter causes friction with the plane. To prevent motion in the body a force must be supplied acting in the direction T and equal to that acting toward A.

The force acting toward A is computed as W sine a in which W equals the weight of the body and a equals the angle the plane makes with the horizontal. The force acting toward B is computed as W cos. a. The angular range of an inclined plane is from level or 0° to vertical or 90°. The sine of an angle of 1° equals the cosine of an angle of 89°, and their values are complementary throughout this range. Table 53 has been compiled from this relationship, in which the weight W is assumed as 100 units and the values of the forces acting toward A and B are computed for each degree of the angular range. The values thus represent a percentage of weight W.

For example, a weight of 100 pounds on a plane of 18° will exert (from the table) a force of 30.9 pounds downward parallel to the plane (A) and 95.11 pounds normal to the plane (B). In other words, on an 18° plane the force tending to move a body down the plane is 30.9 percent of its weight, and the force acting to produce friction is 95.11 percent of that weight.

In order to hoist the body up the incline a force must be applied in direction T equal to that acting in the direction A plus the friction caused by the force acting toward B.

The weight of the body on the plane is represented by the sum of the weight of the empty car or train, the weight of the load carried by car or train, and the weight of the haulage rope. The car and load weights will remain constant for the entire length of the plane, but the weight of the haulage rope will vary as the car is moved. It will be a maximum when the loaded car is at the bottom of the incline and a minimum when the car is at the top. Since the capacity of the hoist must be computed when the load is the greatest, the weight of the rope should be taken at the maximum.

The friction caused by the force acting toward B affects both the resistance of the car and its load and the haulage rope. The car friction can be computed the same as the friction of a car used with a locomotive as the motive power, except that the weight of the car will vary with the force acting to produce friction, which varies as the cosine of the plane angle.

The friction of the haulage rope will depend upon the length of rope in contact with the plane, the nature of the plane surface, and whether idler rollers are used to keep the rope above the plane surface. The length of rope in contact with the plane will depend upon the sag of the rope, which in turn is governed by the span, tension, and weight of the rope per foot of length, and the height above the plane surface of the point of attachment to the car and upper sheave. Obviously local conditions will govern the amount of rope friction, and computations must be limited to each particular installation.

The sag in horizontal haulage ropes may be computed from the following formula:

$$D = \frac{S^2 W}{8 T},$$

in which

D = deflection or sag, in feet;
S = length of span, in feet;
W = weight of the rope per foot, in pounds; and
T = tension on the rope, in pounds.

TABLE 53.- Values of A and B in percent of gross weight

A, degrees	Percent of W	B, degrees	A, degrees	Percent of W	B, degrees	A, degrees	Percent of W	B, degrees
Level....	0.00	90	....	....	.....	....	....	....
1.........	1.75	89	31	51.50	59	61	87.46	29
2.........	3.49	88	32	52.99	58	62	88.30	28
3.........	5.23	87	33	54.46	57	63	89.10	27
4.........	6.98	86	34	55.92	56	64	89.88	26
5.........	8.72	85	35	57.36	55	65	90.63	25
6.........	10.45	84	36	58.78	54	66	91.36	24
7.........	12.19	83	37	60.18	53	67	92.05	23
8.........	13.92	82	38	61.57	52	68	92.72	22
9.........	15.64	81	39	62.93	51	69	93.36	21
10.........	17.37	80	40	64.28	50	70	93.97	20
11.........	19.08	79	41	65.61	49	71	94.55	19
12.........	20.79	78	42	66.91	48	72	95.11	18
13.........	22.50	77	43	68.20	47	73	95.63	17
14.........	24.19	76	44	69.47	46	74	96.13	16
15.........	25.88	75	45	70.71	45	75	96.59	15
16.........	27.56	74	46	71.93	44	76	97.03	14
17.........	29.24	73	47	73.13	43	77	97.44	13
18.........	30.90	72	48	74.31	42	78	97.82	12
19.........	32.56	71	49	75.47	41	79	98.16	11
20.........	34.20	70	50	76.60	40	80	98.48	10
21.........	35.84	69	51	77.71	39	81	98.77	9
22.........	37.46	68	52	78.80	38	82	99.03	8
23.........	39.07	67	53	79.86	37	83	99.26	7
24.........	40.67	66	54	80.90	36	84	99.45	6
25.........	42.26	65	55	81.91	35	85	99.62	5
26.........	43.84	64	56	82.90	34	86	99.76	4
27.........	45.40	63	57	83.87	33	87	99.86	3
28.........	46.95	62	58	84.80	32	88	99.94	2
29.........	48.48	61	59	85.72	31	89	99.98	1
30.........	50.00	60	60	86.60	30	90	100.00	Level

Table 54 has been computed from this formula to show the sag for various spans and various amounts of tension for a rope weighing 1 pound per foot. The sag for other ropes may be computed by multiplying the figures given in the table by the weight per foot of the rope.

Tables 51 and 52 give the approximate weights per foot and breaking strengths of ropes of various diameters.

The sag in haulage ropes used on planes in which one end of the span is higher than the other will vary somewhat from that calculated by the formula, but the variation will be insufficient to affect seriously the computation for sand and gravel haulage.

TABLE 54.- Sag in feet for wire rope weighing 1 pound per foot

Span, feet	Tension, pounds											
	100	200	300	400	500	1,000	5,000	10,000	20,000	30,000	40,000	50,000
100	12.5	6.25	4.17	3.13	2.50	1.25	0.25	0.13	0.06	0.04	0.03	0.03
150	28.1	14.05	9.37	7.00	5.63	2.81	.56	.28	.14	.09	.07	.06
200	50.0	25.00	16.67	12.50	10.00	5.00	1.00	.50	.25	.17	.13	.10
250	78.1	39.05	26.03	19.50	15.62	7.81	1.56	.78	.39	.26	.20	.16
300	112.5	56.25	37.50	28.25	22.50	11.25	2.25	1.13	.56	.37	.28	.23
350	...	76.60	51.10	38.80	30.60	15.30	3.06	1.53	.77	.51	.39	.30
400	...	100.00	66.67	50.00	40.00	20.00	4.00	2.00	1.00	.67	.50	.40
450	...	126.50	84.40	63.25	50.60	25.30	5.06	2.53	1.27	.84	.63	.50
500	...	156.25	104.20	78.13	62.50	31.25	6.25	3.13	1.56	1.04	.78	.62
550	...	189.00	126.00	94.50	75.60	37.80	7.56	3.78	1.89	1.26	.95	.75
600	...	...	...	112.50	90.00	45.00	9.00	4.50	2.25	1.50	1.13	.90
650	...	...	...	132.00	105.60	52.80	10.56	5.28	2.64	1.76	1.32	1.06
700	...	...	...	153.00	122.50	61.25	12.25	6.13	3.06	2.04	1.53	1.23
750	...	...	...	176.00	140.60	70.30	14.06	7.03	3.51	2.34	1.76	1.41
800	...	...	...	200.00	160.00	80.00	16.00	8.00	4.00	2.70	2.00	1.60
850	...	...	...	...	...	90.30	18.06	9.03	4.51	3.01	2.25	1.80
900	...	...	...	...	...	101.00	20.20	10.10	5.05	3.37	2.52	2.02
950	...	...	...	...	...	113.00	22.60	11.30	5.56	3.80	2.78	2.26
1,000	...	...	...	...	...	125.00	25.00	12.50	6.25	4.17	3.13	2.50
1,100	...	...	...	...	...	151.00	30.20	15.10	7.55	5.03	3.77	3.02
1,200	...	...	...	...	...	180.00	36.00	18.00	9.00	6.00	4.50	3.60
1,300	...	...	...	...	...	211.00	42.20	21.10	10.55	7.03	5.27	4.22
1,400	...	...	...	...	...	245.00	49.00	24.50	12.25	8.17	6.13	4.90
1,500	...	...	...	...	...	281.00	56.20	28.10	14.05	9.37	7.03	5.62
1,600	...	...	...	...	...	320.00	64.00	32.00	16.00	10.67	8.00	6.40
1,700	...	...	...	...	...	...	72.25	36.13	18.06	12.04	9.03	7.23
1,800	...	...	...	...	...	...	81.00	40.50	20.25	13.50	10.13	8.10
1,900	...	...	...	...	...	...	90.30	45.15	22.57	15.05	11.28	9.03
2,000	...	...	...	...	...	...	100.00	50.00	25.00	16.67	12.50	10.00
3,000	...	...	...	...	...	...	225.00	112.50	56.25	37.50	28.13	22.50

The approximate length of rope which drags on the plane can be calculated from the sag as found for any particular installation. The height of the car coupling varies with the car design, ranging from 12 to 34 1/2 inches and averaging roughly 24 inches. The height of the upper sheave above the ground varies with each installation. This sheave may be installed below the rails so that the car can run over it, or it may be in a building or on a structure above the track allowing the car to run under it. Customarily the sheave is placed below the rails so that the rope passes level with the top of the rail. In such instances, if the tension is sufficient the rope when starting the loads will assume a position in a straight line between sheave and car coupling and will not drag for any portion of its length. This, of course, is an extreme condition not met in practice. If the average height of the car coupling is 24 inches and the sheave is at the ground surface, the maximum sag permissible without dragging will be 12 inches. If the weight per foot, span, and tension are known for any particular installation, the sag can be calculated from table 54, and from the basic formula, $D = \frac{S^2W}{8\ T}$, the span corresponding to a sag of 1 foot can also be calculated.

The difference between the span for a 1-foot sag and the actual span will give the approximate dragging length at the start of the trip. The dragging length will be reduced as the car moves up the plane, and consequently the rope friction will be reduced.

The car or train resistance will depend upon the condition of the cars and track and will range from a minimum of 10 pounds per ton of gross car weight for specially built plane cars in first-class condition to 50 pounds or more for poorly maintained pit cars.

The frictional resistance of the rope will depend upon the type and spacing of idler rollers, if used, or the condition of the roadbed or ties on which the rope drags. For the most efficient idlers the resistance may be as low as 100 pounds per ton of rope weight, and for dragging over rough, poorly ballasted ties it may be as great as 1,000 pounds per ton of rope weight.

Table 55 gives the friction and gravity components of unit car and rope weights for various angles of plane inclination.

TABLE 55.-Gravity and friction components of loads on inclines

Plane inclination		Rope tension due to gravity from 2,000 pounds of total load (car+gravel + rope), pounds	Rope tension due to resistance of 2,000 pounds of gross car weight (car+gravel), pounds		Rope tension due to friction of 2,000 pounds of rope weight, pounds	
Degrees	Percent		10 pounds per ton	50 pounds per ton	100 pounds per ton	1,000 pounds per ton
1	1.75	35	10	50	100	1,000
2	3.5	70	10	50	100	999
3	5.2	105	10	50	100	999
4	7.0	140	10	50	100	998
5	8.7	174	10	50	100	996
6	10.5	209	10	50	100	995
7	12.3	244	10	50	99	993
8	14.0	278	10	50	99	990
9	15.8	312	10	49	99	988
10	17.6	347	10	49	99	985
11	19.4	382	10	49	98	982
12	21.3	416	10	49	98	978
13	23.1	450	10	49	97	974
14	25.0	484	10	49	97	970
15	26.8	518	10	48	97	966
16	28.7	551	10	48	96	961
17	30.6	584	10	48	96	956
18	32.5	618	10	48	95	951
19	34.4	651	9	47	95	946
20	36.4	684	9	47	94	940
21	38.4	716	9	47	93	934
22	40.4	749	9	46	93	927
23	42.4	781	9	46	92	921

TABLE 55.- Gravity and friction components of loads on inclines - Continued

Plane inclination		Rope tension due to gravity from 2,000 pounds of total load (car+gravel + rope), pounds	Rope tension due to resistance of 2,000 pounds of gross car weight (car+gravel), pounds		Rope tension due to friction of 2,000 pounds of rope weight, pounds	
Degrees	Percent		10 pounds per ton	50 pounds per ton	100 pounds per ton	1,000 pounds per ton
24	44.5	814	9	46	91	914
25	46.6	845	9	45	91	906
26	48.8	877	9	45	90	899
27	51.0	908	9	45	89	891
28	53.2	939	9	44	88	883
29	55.4	970	9	44	88	875
30	57.7	1,000	9	43	87	866
31	60.0	1,030	9	43	86	857
32	62.5	1,060	8	42	85	848
33	64.9	1,089	8	42	84	839
34	67.5	1,118	8	41	83	829
35	70.0	1,147	8	41	82	819
36	72.7	1,176	8	40	81	809
37	75.4	1,204	8	40	80	799
38	78.1	1,231	8	39	79	788
39	81.0	1,258	8	39	78	777
40	83.9	1,286	8	38	77	766
41	86.9	1,312	8	38	76	755
42	90.0	1,338	7	37	74	743
43	93.2	1,364	7	37	73	731
44	96.6	1,390	7	36	72	719
45	100	1,414	7	35	71	707
46	103	1,439	7	35	70	695
47	107	1,463	7	34	68	682
48	111	1,486	7	33	67	669
49	115	1,510	7	33	66	656
50	119	1,532	6	32	64	643
51	123	1,554	6	31	63	629
52	128	1,576	6	31	62	616
53	133	1,597	6	30	60	602
54	138	1,618	6	29	59	588
55	143	1,638	6	29	57	574
56	148	1,658	6	28	56	559
57	154	1,678	5	27	55	545
58	160	1,696	5	27	53	530
59	166	1,714	5	26	52	515
60	173	1,732	5	25	50	500

TABLE 55.- Gravity and friction components of loads on incline - Continued

Plane inclination		Rope tension due to gravity from 2,000 pounds of total load (car+gravel + rope), pounds	Rope tension due to resistance of 2,000 pounds of gross car weight (car+gravel), pounds		Rope tension due to friction of 2,000 pounds of rope weight, pounds	
Degrees	Percent		10 pounds per ton	50 pounds per ton	100 pounds per ton	1,000 pounds per ton
61	180	1,750	5	24	49	485
62	188	1,766	5	24	47	469
63	196	1,782	5	23	45	454
64	205	1,798	4	22	44	438
65	214	1,813	4	21	42	423
66	225	1,827	4	20	41	407
67	236	1,841	4	20	39	391
68	247	1,854	4	19	38	375
69	260	1,867	4	18	36	358
70	275	1,880	3	17	34	342
71	290	1,891	3	16	33	326
72	308	1,902	3	15	31	309
73	327	1,913	3	15	29	292
74	349	1,922	3	14	28	276
75	373	1,932	3	13	26	259
76	401	1,941	2	12	24	242
77	433	1,949	2	11	23	225
78	470	1,956	2	10	21	208
79	514	1,963	2	10	19	191
80	567	1,970	2	9	17	174
81	631	1,976	2	8	16	156
82	711	1,981	1	7	14	139
83	814	1,985	1	6	12	122
84	951	1,989	1	5	11	105
85	1,143	1,992	1	4	9	87
86	1,430	1,995	1	3	7	70
87	1,908	1,997	1	3	5	52
88	2,864	1,998	0	2	4	35
89	5,729	1,999	0	1	2	17
90	Infinity	2,000	0	0	0	0

Besides the tension due to gravity and the car and rope frictional resistances, the haulage rope is subject to additional tension caused by acceleration.

Acceleration is usually expressed as an increase of speed in feet per second for each second acceleration lasts. It may be computed from the formula:

$$a = v/t$$

in which

v = velocity in feet per second,
a = acceleration in feet per second per second, and
t = time in seconds.

The tension due to acceleration can be computed from the formula:

$$F = Wa/g$$

in which

W = gross weight of car, load, and rope, pounds;
a = acceleration in feet per second per second;
g = acceleration due to gravity = 32.16; and
F = acceleration tension, pounds.

Combining the two formulas,

$$F = Wv/gt$$

Table 56 has been computed to present the accelerative force in pounds per ton of gross load for various accelerative periods and final velocities.

TABLE 56.- Accelerative force required for 2,000 pounds gross load, pounds

Acceleration period, seconds	Velocity, feet per minute												
	100	200	300	400	500	600	700	800	900	1,000	1,250	1,500	2,000
5	20.7	41.5	62.2	83.0	104.0	124.0	145.0	166.0	187.0	207.0	259.0	311.0	415.0
6	17.3	34.5	1.8	69.1	86.4	104.0	121.0	138.0	155.0	173.0	216.0	259.0	345.0
7	14.8	29.6	44.4	59.2	74.0	88.9	104.0	118.0	133.0	148.0	185.0	222.0	296.0
8	13.0	25.9	38.9	51.8	64.8	77.8	90.7	104.0	117.0	130.0	162.0	194.0	259.0
9	11.5	23.0	34.6	46.1	57.6	69.1	80.7	92.2	104.0	115.0	144.0	173.0	230.0
10	10.4	20.7	31.1	41.5	51.9	62.2	72.6	83.0	93.4	104.0	130.0	156.0	207.0
15	6.9	13.8	20.7	27.6	34.5	41.5	48.4	55.3	62.2	69.1	86.3	104.0	138.0
20	5.2	10.4	15.5	20.7	25.9	31.1	36.3	41.5	46.6	51.8	64.8	77.7	104.0
25	4.2	8.3	12.5	16.6	20.7	24.9	29.1	33.2	37.4	41.5	51.9	62.2	83.0
30	3.5	6.9	10.4	13.8	17.3	20.7	24.2	27.7	31.1	34.6	43.3	51.9	69.2
35	3.0	5.9	8.9	11.8	14.8	17.8	20.7	23.7	26.6	29.6	37.0	44.4	59.2
40	2.6	5.2	7.8	10.4	13.0	15.5	18.1	20.7	23.3	25.9	32.4	38.9	51.8
45	2.3	4.6	6.9	9.2	11.5	13.8	16.1	18.4	20.7	23.0	28.8	34.5	46.0
50	2.1	4.1	6.2	8.3	10.4	12.4	14.5	16.6	18.6	20.7	25.9	31.1	41.4
55	1.9	3.8	5.6	7.5	9.4	11.3	13.2	15.0	16.9	18.8	23.5	28.2	37.6
60	1.7	3.5	5.2	6.9	8.7	10.4	12.1	13.8	15.6	17.3	21.6	26.0	34.6

The distance the car travels during the accelerative period may be computed from the following formula:

$$S = vt/2$$

in which

S = distance traveled in feet,
v = final velocity in feet per second, and
t = acceleration time period in seconds.

Table 57 has been compiled to present the distance traversed by a car for various accelerative periods and final velocities.

The horsepower required in engine-plane duty is a maximum when the loaded car is being started and accelerated at the foot of the incline. Horsepower may be computed from the following formula:

$$HP = TV/33,000$$

in which

T = total tension in pounds, including acceleration stress; and
V = final velocity in feet per minute.

From these formulas and tables it is believed that the capacity of any plane can be computed or the equipment designed to fit a desired capacity. Two examples have been worked out for illustration.

TABLE 57.- Distance covered in feet for various accelerative periods and final velocities (s = vt/2); initial velocity = 0

Acceleration period seconds	Final velocity, feet per minute												
	100	200	300	400	500	600	700	800	900	1,000	1,250	1,500	2,000
5	4.17	8.3	12.5	16.7	20.8	25.0	29.2	33.3	37.5	41.7	52.1	62.5	83.3
6	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	65.0	75.0	100
7	5.83	11.7	17.5	23.3	29.2	35.0	40.8	46.6	52.5	58.3	72.9	87.5	117
8	6.67	13.3	20.0	26.7	33.3	40.0	46.7	53.3	60.0	66.7	83.3	100	133
9	7.50	15.0	22.5	30.0	37.5	45.0	52.5	60.0	67.5	75.0	93.8	113	150
10	8.33	16.7	25.0	33.3	41.7	50.0	58.3	66.7	75.0	83.3	104	125	167
15	12.50	25.0	37.5	50.0	62.5	75.0	87.5	100	113	125	156	188	250
20	16.67	33.3	50.0	66.7	83.3	100	117	133	150	167	208	250	333
25	20.83	41.7	62.5	83.3	104	125	146	167	188	208	260	313	417
30	25.00	50.0	75.0	100	125	150	175	200	225	250	313	375	500
35	29.17	58.3	87.5	117	146	175	204	233	263	292	365	438	583
40	33.33	66.7	100	133	167	200	233	267	300	333	417	500	667
45	37.50	75.0	113	150	188	225	263	300	338	375	469	563	750
50	41.67	83.3	121	167	208	250	292	333	375	417	521	625	833
55	45.83	91.7	138	183	229	275	321	367	413	458	573	688	917
60	50.00	100	150	200	250	300	350	400	450	500	625	750	1,000

Example 10.- Assume that an operator wishes to install a simple engine plane to hoist 1,000 tons per day of 8 hours from his pit through a vertical distance of 100 feet and that the plane length must approximate 300 feet in horizontal distance. Pit cars will be hoisted singly and weigh 4 tons each, with a capacity of 6 cubic yards or 9 tons.

$$\frac{1,000}{8} = 125 \text{ tons hourly capacity.}$$

$$\frac{125}{9} = 14 \text{ carloads hourly or a round trip on the plane of}$$

$$\frac{60}{14} = 4.3 \text{ or, say, 4 minutes.}$$

If 30 seconds is allowed to dump the car and a like interval to change the rope from one car to another at the foot of the incline, the traveling time per trip must be 3 minutes, or 1.5 minutes each way, assuming equal speed up and down.

The plane has an inclination of approximately 33 1/3 percent or, say, 18°. From trigonometry the inclined length equals the vertical height divided by the sine of the angle. Table 53 shows trigonometric sines and cosines of angles represented as percent. The sine of 18° from the table is 0.3090. Then

$$\frac{100}{0.3090} = 324 \text{ feet, or the inclined length of the plane.}$$

The horizontal length, again from trigonometry, equals the inclined length multiplied by the cosine of the angle. From table 53 the cosine of 18° is 0.9511. Then

$$324 \times 0.9511 = 308 \text{ feet, or the horizontal length.}$$

Since this is only slightly greater than the 300 feet assumed as limiting the horizontal length, the plane will be considered as inclined at an angle of 18° and as 324 feet long.

The car must then travel 324 feet in 1.5 minutes or 90 seconds, or at an average speed of 216 feet per minute.

Assuming that the acceleration period is 10 seconds and that the time required for deceleration is the same, the car will be traveling at constant speed for 90 - 10 - 10 = 70 seconds.

From table 57 a car starting from rest and attaining a speed of 250 feet per minute in 10 seconds will have traveled $\frac{25 + 16.7}{2} = 20.8$ feet. Then 324 - 20.8 - 20.8 = 282.4 feet is to be covered at constant speed in 70 seconds, or 242 feet per minute. Therefore, the hoist should be capable of a drum speed of 250 feet per minute.

The gross weight of the loaded car is

	Tons
Car......	4
Gravel	9
Total	13

If the weight of the rope is disregarded for the moment, reference to table 55 shows that the rope tension due to gravity of 1 ton on an 18° plane is 618 pounds and the car re-

sistance (at 50 pounds per ton) is 48 pounds, or a total tension due to car and load of 666 pounds. From table 56 the accelerative force required to bring 1 ton of load to a speed of 250 feet per minute in 10 seconds will be $\frac{20.7 + 31.1}{2} = 25.9$ pounds. Hence the total tension due to the load is (618 + 48 + 25.9) x 13 tons = 8,995 pounds or 4.5 tons.

As this is a fairly flat plane a factor of safety of 7 is required. The rope then should have a minimum breaking strength of 4.5 x 7 = 31.5 tons. From table 52, a 1-inch, plow-steel haulage rope has a breaking strength of 34.8 tons or more than the minimum required. Therefore a 1-inch rope is selected.

The tension on the hoist can then be computed as follows:

	Pounds
Car weight..................	8,000
Gravel weight..............	18,000
324 feet of 1-inch rope	488
Gross load...............	26,488

Reference to table 54 shows that a rope weighing 1 pound per foot under 10,000 pounds tension on a 350-foot span will sag 1.53 feet. Therefore a 1-inch rope weighing 1.5 pounds per foot may be calculated to sag 1.5 x 1.53 or 2.25 feet. The span required for a 1-foot sag is

$$S = \sqrt{\frac{8\,DT}{W}} = \sqrt{\frac{8 \times 1 \times 10{,}000}{488}} = 164 \text{ feet.}$$

324 - 164 = 160 feet of rope dragging.

160 x 1.5 = 240 pounds, weight of dragging rope.

From tables 55 and 56, the various tensions are as follows:

	Pounds
Gravity, $\frac{26{,}488}{2{,}000} \times 618$.................. =	8,180
Car resistance, $\frac{26{,}000}{2{,}000} \times 48$........ =	624
Rope friction, $\frac{240}{2{,}000} \times 951$.......... =	114
Acceleration, $\frac{26{,}488}{2{,}000} \times 25.9$........ =	343
Maximum tension....................	9,261

At the minimum resistance offered by cars in best condition and with adequate rope idlers the tension would be

	Pounds
Gravity.. =	8,180
Car resistance, $\frac{26{,}000}{2{,}000} \times 10$........ =	130
Rope resistance, $\frac{240}{2{,}000} \times 95$........ =	11
Acceleration.. =	343
Total..	8,664

This maximum tension is exerted for only the acceleration period or 10 seconds. Hence the indicated horsepower required is

$$\text{I.hp.} = \frac{TV}{33{,}000} = \frac{9{,}261 \times 250}{33{,}000} = 70.2, \text{ and}$$

$$\text{I.hp.} = \frac{8{,}664 \times 250}{33{,}000} = 65.6.$$

At 75-percent efficiency the power required would be 88.5 to 94 hp.

From table 52 the hoist drum should be 6 feet in diameter for a 1-inch haulage rope, but for hoisting rope it might be 4 feet in diameter.

With haulage rope the drum speed would be 13.26 r.p.m., and with hoisting rope it would be 19.9 r.p.m. to obtain the required rope speed of 250 feet per minute.

The time cycle with such equipment will be as follows:

		Feet	Seconds
Hoisting:			
	Acceleration	20.8	10
	Constant speed	282.4 at 250 f. p.m.	68
	Deceleration	20.8	10
	Total	324.0	88
Dumping			30
Lowering (controlled by brake but assumed same as hoisting)			88
Changing rope			30
Total cycle (3 minutes 56 seconds)			236

Then $9 \times \frac{3{,}600 \times 8}{236} = 1{,}100$ tons per day, or 10 percent more than required in the problem.

This margin is small but can easily be enlarged by releasing the brake and speeding up the downhill return of the empty car.

Example 11.- The same conditions are assumed as in example 10, except that two cars and ropes are used and hoisted in balance.

Starting with a loaded car at the bottom of the incline and an empty car at the top, the loads on the two ropes are as follows:

	Up trip, pounds	Down trip, pounds
Car weight	8,000	8,000
Gravel weight	18,000	
Rope weight	488	
Total	26,488	8,000

The tensions due to gravity and frictional resistances are

	Up trip, pounds	Down trip, pounds
Gravity, $\frac{26,488}{2,000} \times 618$ =	8,180	....
$\frac{8,000}{2,000} \times 618$ =	....	2,472
Car resistance, $\frac{26,000}{2,000} \times 48$ =	624	....
$\frac{8,000}{2,000} \times 48$ =	....	-192
Rope friction, $\frac{240}{2,000} \times 951$ =	114	0
Acceleration, $\frac{26,488}{2,000} \times 25.9$ =	343	....
$\frac{8,000}{2,000} \times 25.9$ =	....	103.6
Total	9,261	2,383.6

The unbalanced pull on the hoist drum is then

$$9,261 - 2,383.6 = 6,877.4 \text{ pounds.}$$

The maximum indicated horsepower is

$$\text{I.hp.} = \frac{TV}{33,000} = \frac{6,877.4 \times 250}{33,000} = 52 \text{ hp.}$$

With best cars and idlers the unbalanced pull would be

$$8,664 - 2,535.6 = 6,128.4 \text{ pounds, and the indicated horsepower } \frac{6,128.4 \times 250}{33,000} = 46.5.$$

At 75-percent efficiency the power required would range from 62 to 70 hp.

Balanced hoisting thus saves about 25 hp. or nearly 30 percent of that required for the simple engine plane.

The loaded car would be dumped while the rope was being changed at the bottom of the plane. Hence the time cycle would be the same as that for a single-track plane, but there would be 2 cars dumped instead of 1 car. The capacity would thus be doubled.

Remote-Control Haulage

Remote-control haulage or centrally controlled haulage systems have not, to the author's knowledge, been used in sand and gravel pits. They have been applied successfully to rock-quarry haulage, and since there is no fundamental reason why they should not be applied to gravel pits a brief discussion is included.

This type of haulage system consists of the operation by remote control of a number of self-propelled, burden-bearing cars by one man from a centrally located observation tower. Where local topography or construction prevents a view of the entire haulage route from one control point, 2 towers and 2 men are used.

The system is powered by electricity, the majority of installations using direct current supplied through a third or power rail. Recently alternating current has been utilized

successfully with two power rails. With either current the system is so designed that the entire haulage route is divided into several sections, any one or all of which may be energized at one time. Thus sections on which no cars are traveling may be cut out of the circuit automatically and may carry no current.

The cars used in these systems are built from designs made for each installation. Hence there is no standardization of design, except perhaps as to minor details. Each car consists of a cargo-carrying hopper up to 50 tons in capacity, which may be designed to dump to either side or end as desired, mounted on a heavy frame carried on a narrow- or standard-gage wheel base, usually of two 4-wheel trucks. The motive power is supplied by electric motors mounted on the trucks and geared to the axles. With direct current 2 to 4 motors are used, half the number driving the car in one direction and half in the other. Thus half the motors are idle with this type of current. With alternating current 2 motors are used, and the direction of travel is changed by reversing the direction of rotation of the motor through phase control. Cars using both types of current are fitted with brakes which automatically set when the current is cut off.

Haulage tracks with these systems can be either narrow or standard gage, and curves and grades suitable for locomotive haul can be negotiated.

Both systems are subject to the disadvantage of added difficulty and cost in shifting tracks when such shifts are necessary frequently to follow the moves of the excavator. This disadvantage is largely removed where it is possible to design the haulage route as a circle or ellipse.

Centrally controlled haulage systems are comparatively high in first cost and are not suited to small tonnage requirements. Where production is large enough the operating costs are reported to be less than those with locomotive haul.

These systems, like trolley locomotive systems, require well-maintained, electrically bonded tracks.

As they are controlled from 1 or 2 central towers, the operating labor is reduced to a minimum. Where the control tower is at such a distance that accurate spotting of the cars at the excavator becomes difficult, subcontrol stations can be set up to be operated by the shovel runner.

Operators of these systems claim that less rolling equipment is necessary with them than with locomotive haul and that because of more regularity in the time cycle less delay occurs at the shovel due to lack of haulage equipment.

The operation of centrally controlled systems is limited to large dry operations having a source of relatively cheap electric power.

For further details on this type of haulage the reader is referred to Bureau of Mines Information Circulars 6498 and 6513, describing the operations of the Trinity Portland Cement Co. at their Dallas and Fort Worth quarries, and to an article on pages 90-93 of the October 10, 1931 issue of Rock Products, entitled "New Quarry Haulage System Uses Alternating Current."

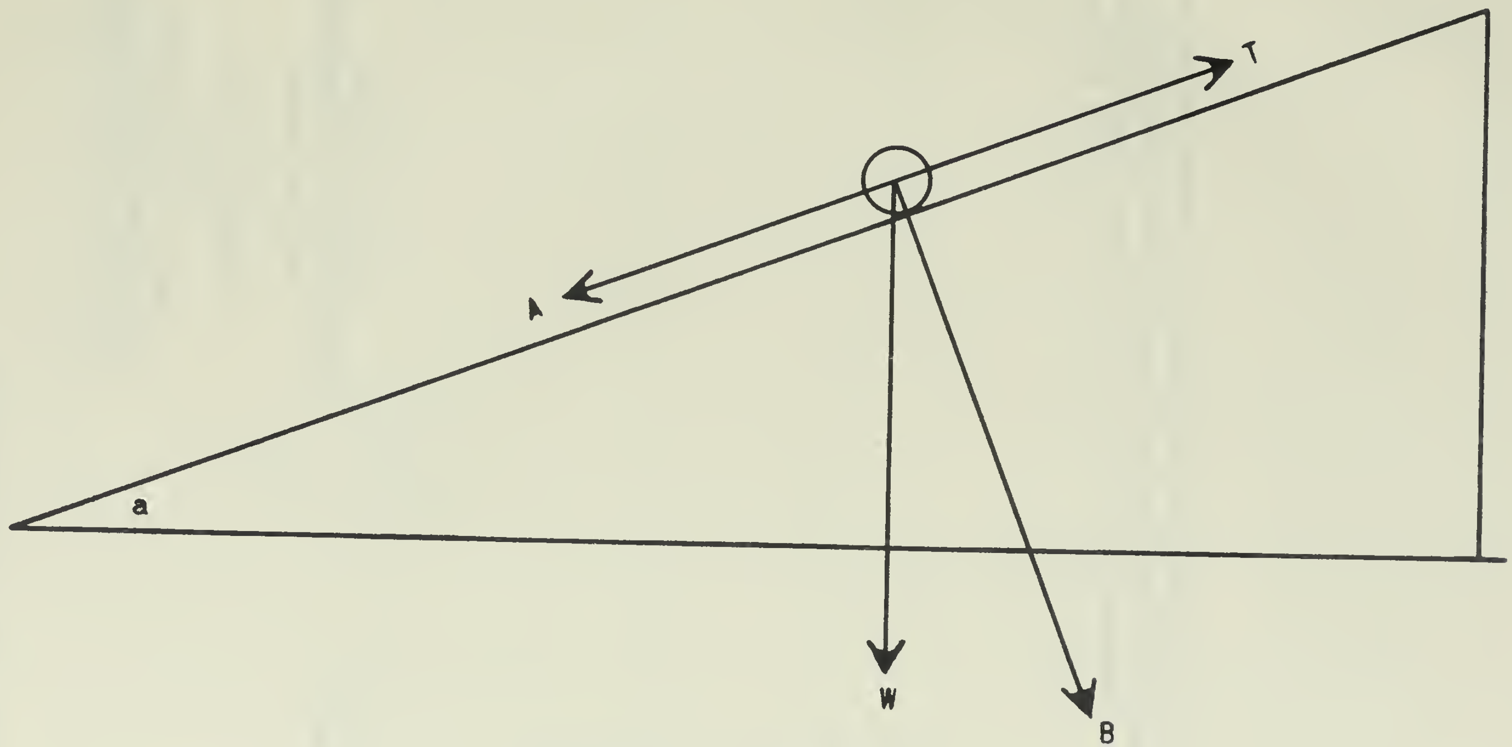

Figure 18.- Inclined plane.

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Department of the Interior

UNITED STATES BUREAU OF MINES
John W. Finch, Director

INFORMATION CIRCULAR

REVIEW OF LITERATURE ON EFFECTS OF BREATHING DUSTS WITH SPECIAL REFERENCE TO SILICOSIS

PART III-A

CHAPTER 5. ECONOMIC AND LEGAL ASPECTS OF DUST DISEASE IN INDUSTRY (SECTIONS 1 AND 2)

BY

D. Harrington and Sara J. Davenport

I. C. 6857,
October 1935.

INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

REVIEW OF LITERATURE ON EFFECTS OF BREATHING DUSTS WITH SPECIAL REFERENCE TO SILICOSIS[1]

PART III-A

By D. Harrington[2] and Sara J. Davenport[3]

CONTENTS

This circular presents Part III-A of a series reviewing the literature on effects of breathing dusts with special reference to silicosis; it deals with the economic and legal aspects of dust diseases in industry; Part III-B will contain data on the status and cost of compensation for silicosis. Parts I and II of the series have been issued as Information Circulars 6835, 6840, and 6848; Part I defines and classifies dusts, indicates sources of exposure, and describes the physiological effects of breathing dusts; Part II-A discusses the principal dust factors producing pulmonary pathology and methods of determination of dust in air; and Part II-B presents data on the engineering and medical control in the prevention of dust diseases and general recommendations for their control in industry.

A summary and general conclusions will complete the series.

1/ The Bureau of Mines will welcome reprinting of this information circular, provided the following footnote acknowledgment is used: "Reprinted from U.S. Bureau of Mines Information Circular 6857."

2/ Chief, health and safety branch, U.S. Bureau of Mines.

3/ Principal translator, U.S. Bureau of Mines.

CHAPTER V. ECONOMIC AND LEGAL ASPECTS OF DUST DISEASE IN INDUSTRY

Section 1.- The Economic Menace of Dust Diseases in Industry

Recently dust and dust diseases -- especially silicosis -- have jumped from obscure, scarcely recognized diseases hidden for centuries in the chests of workers in various dusty industries to front-page headlines in the daily press and to wide discussion in the technical journals of the United States and other countries. This unusual news value is not due primarily to the sudden realization of the presence in our industrial midst of a great health hazard but to a rude awakening to the fact that a very important economic hazard is menacing industry, even to the extent in some instances of threatening its very existence. Such headlines and statements as the following indicate the seriousness of the situation:

Silicosis Damage Suits Reach Illinois Courts

The $25,000-damage suit of a former employee of a silica company has been in progress in a circuit court in Illinois. The plaintiff alleges he contracted silicosis while employed by the company.

Meanwhile, 2 similar suits, each asking $50,000 damages, brought by former workers of another silica company, were dismissed by the judge. It was said that a settlement had been effected out of court (377).

28 Alleged Silicosis Victims Ask Damages - Total of $982,500 Demanded

Damages totaling $982,500 are being sought in 28 separate suits filed by employees and former employees of a silica company in Illinois, following their alleged contraction of silicosis while working in the plant and silica-sand quarries of the company.

Included among the plaintiffs are 10 who are demanding damages of $25,000, $50,000, $37,500, $35,000, $25,000, $10,000, $10,000, $45,000, $20,000, and $25,000.

The almost wholesale filing of the suits follows the recent decisions of courts in Illinois wherein former workers who contracted silicosis were awarded substantial claims for damages from silica-sand operators in that vicinity (378).

Awards Silicosis Victim $10,000 in Damage Suit

A plaintiff was awarded $10,000 damages recently by a circuit-court jury as the result of a suit in which he alleged that he had contracted silicosis during his employment with a silica-sand company.

This suit is the first ever prosecuted under the workmen's compensation law in Illinois involving the disease (379).

Court Awards Silicosis Victim $17,000 Damages

A patient in a sanitarium suffering from silicosis was awarded $17,000 damages against his former employer, a silica-sand company of Illinois, by a circuit-court jury on February 16. The plaintiff sued for $25,000, and the case had been on trial for more than 2 weeks. Counsel for the defense moved that the verdict be set aside and filed a motion for a new trial. Both were denied. An appeal to the Illinois Supreme Court is pending.

A few months ago another employee of the company obtained a $10,000 judgment in a similar suit. Only recently the judge denied the company a new trial. This case, too, is to be appealed to the supreme court, it is reported (380).

Victim Sues to Collect Insurance for Silicosis

A former employee of a silica plant has filed suit against the _____ Life Insurance Co., asking $5,000, alleging that he is entitled to that settlement on account of a total-disability clause in his policy. He claims to have contracted silicosis while working at the plant and has been totally disabled as a result (381).

Silicosis in Certain of Its Legal Aspects

At the present time there are hundreds of suits against industrial concerns throughout the country, predicated on silicosis. In the State of Illinois approximately 200 silicosis cases are pending in the common-law courts. Because of the unemployment situation and the activity of ambulance chasers there probably will be many more, with the resultant closing of industrial plants and a vast economic loss (382).

In Missouri 8 suits for damages from the contraction of silicosis brought against a silica company have been settled out of court for $36,500 (383).

Silicosis and Silicotuberculosis

For instance, in the St. Louis Post-Dispatch of March 19 last it was stated that there were $5,000,000 of claims against a mining company operating in Missouri and that approximately $500,000 had been expended in settling some of these claims. One company (gravel-crushing) had 100 claims among 175 workers; 50 of these had filed suit. There was merit in one fourth of the claims.

Hundreds of claims by workers in lime quarries and lime manufacture and cement have been filed in Missouri. In Illinois 23 suits were filed in 2 days against an abrasive company.

The foregoing gives some idea of the prevalence of silicosis among silica workers. The importance of this subject as an industrial problem not only to the workers but also to the employers is glaringly apparent, and it must be met for the sake of both (384).

Lawyer Tells How Silicosis Suits Developed Here After Friend Died of Disease--Number of Rock-Dust Industries in State Help Explain Hundreds of Cases--Alleged Negligence Basis of Claims

The silicosis damage suit in which the State Supreme Court last Wednesday refused a writ to prohibit trial in St. Louis Circuit Court is one of many constituting a comparatively recent phase of litigation in St. Louis courts.

About 300 such suits are pending. As was told recently in the Post-Dispatch, the total amount represented by these suits and additional claims in the hands of lawyers but not yet sued upon was estimated at $12,000,000 by an investigator for one defendant corporation. The unsuccessful application to the supreme court for a writ of prohibition was made by the defendant company in a number of pending suits. * * * .

Another incident, an unusual defense move which reflects the highly controversial nature of the litigation, was the indictment a few days ago of the attorney. He was charged with "moving, stirring up, and inciting" four persons to file damage suits against the company, which he denies. * * * .

In a number of cases judgments have been returned by trial juries for plaintiffs in amounts up to $20,000, and in some cases the verdict has been for the employing corporation. The validity of each claim rests on proof of two facts, first, that the worker has, or had, silicosis, and, second, that it was contracted through the negligence of the employer. In some cases where the worker has died the claimants are surviving relatives. A charge frequently made against employers is that they have neglected to provide the safety devices and measures required by State law. The silicosis suits have been filed in greatest number in the last 3 years.

An attorney, who has specialized in cases of this kind, gave a Post-Dispatch reporter an interesting account of how his interest was aroused and of his exhaustive study of the disease. Since he first handled a silicosis case 3 years ago he has disposed of about 200 cases for claimants by settlement out of court and 20 by trial. He has 600 to 700 claims now in hand, he said. * * * .

"I have never solicited any of these cases", he continued. "They are brought to me in great numbers, not only by the affected persons, but also by other lawyers. It is possible that some lawyers may solicit such cases and then bring them to me. I don't know. If a man has silicosis which appears to have been contracted through the negligence of his employers I try to get compensation for him. Otherwise I do not take the case" (385).

Cement Plants Fight Silicosis Racket

Does employment in or about a cement mill predispose workers to silicosis or tuberculosis?

That's the question that the cement industry answers in the negative, while certain plaintiffs, appearing more numerous of late, are proceeding to test the issue in the courts.

The first "silicosis" case against a portland-cement manufacturer in Illinois came to trial recently in the circuit court at Chicago. After a solid week of legal combat the case was terminated on March 3, on completion of the plaintiff's evidence, by the court granting the defendant's motion for an instructed verdict.

The court held that the plaintiff had failed to make a prima-facie case. In plain language, the plaintiff's case collapsed in utter defeat before presentation of any evidence whatsoever by the defendant.

Almost simultaneously, the first two "silicosis" cases against a Missouri cement-manufacturing company came to trial in the circuit court at St. Louis and after hard-fought legal contests resulted in victory for the two plaintiffs, in one case carrying a judgment of $25,000 and in the other, $15,000. These suits are sure to be appealed.

The winning of these cases by plaintiffs led to the immediate filing of a number of further suits against the defendant. Concerns in the vicinity other than cement manufacturers face an aggregate of some 300 suits of the same general character. Distinction may be made in the case of the cement manufacturers because of the fact that their dust is known to contain only about 1 percent of free silica and that dust concentrations are far below the determined "danger" point. Consequently in the minds of most of the cement fraternity these suits are purely rackets and must be dealt with as such. * * *.

The industrial-disease racket, though it sprang up like a mushroom, has developed with the strength of a mighty tree to the point where it bids fair to make the liquor, kidnapping, and even the labor rackets look insignificant by comparison of the amounts involved, the losses caused to the public, and the enormous profits received and the small risks incurred by the racketeer (386).

Silicosis Racketeering in Missouri

The Editor: Have read "Cement Plants Fight Silicosis Racket" in your May issue. This is the best exposition I have yet seen in print of what is actually going on. The article gets right down to cases.

Everything therein concerning Missouri conditions is correct, and the writer could have gone still farther in the matter had he so wished.

The latest victim in this State is the fire-clay industry * * * a member of which is being sued for $25,000. As usual the "runner" or hobo attorney picked out the one with the most money. If the "plaintiff" has worked for several companies, as is sometimes the case, the snitch lawyer picks out the company most likely to come through with the money.

We have seven of these, with a mill that has been dustless for years; we got a hung jury on the first and most pitiful case (permanently crippled by syphilitic arthritis, no silicosis). Six of the remaining cases then pulled out voluntarily to the great disgust of the snitches. The other two will probably not come to trial.

As the chemist for one of the principal offenders in St. Louis remarked: "To hell with the chemical analysis; all we need is dust." Any dust will do.

Missouri is one State that industry had better keep out of, for we have no legal protection whatever from these racketeers (387).

"A Missouri Victim."

Silicosis and Mining

Silicosis damage suits reared their heads again in St. Louis last week in the form of the suit of _____ versus _____ Co. A new term is being used by attacking plaintiffs and their attorneys in bringing suits against mining companies, quarries, stone plants, process plants, and any concern where the slightest dust occurs.

In the St. Louis area there are some 2,000 suits pending * * *.

Seeking a more "comprehensive" term, plaintiffs are now using the term "pneumoconiosis", which one attorney described as "covering everything from a nose sniffle to death from tuberculosis."

St. Louis is noted for high damage juries, usually more than sympathetic toward anyone suing a corporation, and defense attorneys allege that a majority of the suits are part of a "racket" instituted by a ring of "lawyers."

Plaintiffs' attorneys contradict these allegations and assert that expert testimony will prove their cases when the 2,000 suits are terminated.

Confined to a great degree to Missouri at present, the suits give warning of their spreading to other points (388).

Lime Employee Wins $22,500 Silicosis Suit -
Suits Pending for $155,000

A motion to set aside the appointment of a receiver for a lime and cement company was upheld February 20 in circuit court. This company had been thrown into receivership February 12 to protect its assets from being wiped out through damage suits brought by former employees who claim to have contracted silicosis while in the company's employ. The president of the company had been appointed receiver for the company on the petition of an unsecured creditor and with the company's consent. The circuit court had also granted an injunction restraining the holder of a $22,500 judgment against the company from obtaining an execution against its property. The injunction also restrained the plaintiffs in other silicosis suits against the company from proceeding with the prosecution of such legal actions and prohibited the filing of a new damage suit against the company. The aggregate amount sought in pending silicosis suits is reported to be $155,000.

The company's assets are said to greatly exceed its liabilities, but its credit had been greatly injured by reason of the judgment, the other suits which are pending, and still others that may be filed by former employees, according to the petition.

During the past 18 months several hundred suits have been filed in the State and Federal courts in Missouri by men and women who claim to have contracted silicosis while formerly employed. The aggregate amount sought in these various suits is placed at $15,000,000, and it is admitted that they would wipe out a number of industrial concerns if all of the plaintiffs were able to obtain judgments for the maximum amounts they are seeking. Lead, cement, and sand companies, glass plants, and flour mills have been among the defendants named in these wholesale suits. In each case the employer is charged with negligence in failing to take proper precautions to prevent employees from being affected by silica poisoning (389).

Silicosis Suit Against Missouri Firm Dismissed

A silicosis suit for $30,000 against a glass company was dismissed February 25 by the Federal judge at St. Louis. The plaintiff said that he had X-ray pictures of his lungs taken at the suggestion of a lawyer. A stipulation which he signed November 1933 at the office of the company was admitted as evidence. At that time he was paid $100 (390).

Silicosis Verdict Awarded Former Plant Employee

A verdict of $10,000 was returned by a jury March 7 in a Missouri circuit court in favor of an employee of a sand company. The award was for personal injuries he was alleged to have suffered from contraction of silicosis while in the company's employ. The plaintiff was employed by the company 12 years ago (391).

Two Silicosis Motions Are Denied by Court

Supreme Court Justice _____ yesterday denied motions of a company to dismiss two $100,000 silicosis complaints pending against it. Two similar motions were denied the previous day in other silicosis actions by Justice _____.

The plaintiffs involved in yesterday's decisions * * * allege they contracted a lung disease as a result of sand-blasting operations.

"Whether the disease contracted by the plaintiff was an accidental injury for which compensation is provided will probably depend upon the testimony of experts and may become a question of fact which can only be determined after trial", Justice _____ decided (392).

Appeals Silicosis Case Court Decision--Company Seeks to Set Aside Order Denying Dismissal

Notice of appeal to the appellate division from a supreme-court decision upholding a plaintiff's right to maintain a common-law action for damages in a silicosis case was filed yesterday by the _____ Co.

The plaintiff is seeking $100,000 damages, alleging he contracted the lung disease called "silicosis" while employed in sand-blasting. The appeal is from an order of Justice _____ issued July 20 denying a motion made by the company for dismissal of the complaint.

Several silicosis suits are awaiting trial, the _____ Co. being defendant in but one (393).

Silicosis in the Courts of New York

It is estimated that several hundred cases asking more than $1,000,000 in damages have been filed in the New York State courts on behalf of workers claiming to have contracted silicosis in the course of their employment (394).

Silicosis in Rochester

Not long ago a deluge of common-law suits for negligence fell upon various industrial employers in Rochester. It came with the suddenness of a tropical hurricane, taking most of them by surprise.

In the beginning it was alleged that the injury was due to "silicosis." Most employers who had heard of this disease at all thought of it chiefly as a disease of miners and quarrymen, with little thought of the possibility that it might arise in a great variety of manufacturing plants, and least of all in a transportation company.

It soon became apparent that someone had been industriously searching the list of employees and ex-employees of a number of companies for those who had died of tuberculosis or other pulmonary diseases, or for those who were in tuberculosis sanatoria, and later for those who might be expected to have silicosis. A large number of these men were given preliminary examinations by one physician on the basis of whose findings suits were filed by the dozen, nearly all being represented by one attorney.

In October 1932 one of these cases went to a jury, which gave a verdict for the plaintiff awarding nearly $14,000 to the widow. In this case it was clearly shown in the evidence that the deceased had died from the rupture of an aortic aneurysm into the oesophagus, that this aneurysm was due to syphilis. It was conceded by the defense that the deceased had tuberculosis. The plaintiff's counsel brought in very weak evidence that silicosis was present; for instance one of his witnesses reported that the ash of the lung of the deceased contained 2.2 percent of silica, an amount which is not more than one seventh of the amount which may be found in the ash of normal lungs.

Following this triumphant demonstration of what a jury might do, Rochester resembled nothing so much as a barnyard just after the swoop of a chicken hawk. A large number of cases were reported to be settled out of court for sums ranging from $2,000 to 4,000. These received due notice from the press with the result that many workmen, mostly unemployed, hastened to be examined in the hope that they, too, might participate in the rapidly growing racket (395).

The Dust Problem and Silicosis

Notable evidence of forward thinking in connection with the health of workers was apparent in the attention given to dusty atmospheres and silicosis at the Annual Safety Congress and Exposition held last week at Chicago. The general subject of dust and silicosis warrants the close study of mining executives in the United States, perhaps more so now than at any time in the past. A case in point is that of a contractor driving a 3-mile tunnel who recently had more than 400 silicosis damage suits filed against him that exceeds $4,000,000 (396).

200 Silicosis Cases Barred From Court

The 200 or more suits instituted by workmen who claimed they were permanently injured by contracting silicosis, a lung disease, while working in the Hawk's Nest dam tunnel, were barred from the courts today by the State's highest tribunal.

The supreme court ruled the actions, for damages of about $5,000,-000 were not filed soon enough or within the statute of limitations.

The workmen were employed in building a water-diversion tunnel for the Hawk's Nest hydroelectric project in New River. * * *.

The plaintiffs claimed they instituted action as soon as they "learned or had cause to suspect" they were suffering from silicosis. The company contended the suits were not filed within the 1-year time limits fixed by State law (397).

Silicosis in Court

Far-reaching effects are indicated in a recent decision in the United States Circuit Court of Appeals, Second Circuit, in a case concerning silicosis. A judgment of $13,903 was affirmed to the plaintiff - the widow of the victim. The justices say: "We think the verdict sufficiently established * * * because the defendant neglected to install a proper exhaust system * * * neglected to prevent the escape of dust by other means; neglected to supply Jacque with a respirator and to instruct him about the danger of contracting silicosis and how to avoid it. * * *. Irrespective of any statute, there is a duty at common law to warn and instruct employees and furnish them with means to avoid inhaling elements that are poisonous or injurious to their health, and there was proof that silica dust is such an element. * * *. In a case like the present the damage was not occasioned by disease inherent in the occupation, but because of neglect to furnish proper instruction and equipment for the prevention of any damage by silica dust."

Contractors engaged in rock drilling and tunneling operations cannot afford to take the risk of being subjected to similar suits by neglecting to protect their workmen from the hazard of silica dust. Dust traps for pneumatic drills have been successfully developed within the past few years that hold the dust concentration down to safe limits. Not only is the drill operator protected, but drilling proceeds at a much faster rate because of the dust-free hole maintained which does not clog the drill. If you want more information about it, ask for it (398).

Silicosis Insurance

A special recess legislative commission of the Massachusetts Legislature have completed a recommendation to force insurance companies writing workingmen's compensation insurance in Massachusetts to insure the employees in foundries and granite-cutting sheds to include the silicosis risk.

While conceding that the insurance companies were not without excuse for seeking to avoid carrying the risk, nevertheless it was held that they were not wholly justified in refusing the risk. It is proposed that in future employees in these industries be subject to annual physical examinations and that if they are found fit then the State Board of Labor and Industries is to issue a certificate of compliance, and insurance companies on the risk must insure. If the employee is unfit, then he will be forced to leave the industry, but will be open to old-age assistance benefits (399).

Surety Underwriters Organize Risk Pool

A group of 25 member companies of the National Bureau of Casualty and Surety Underwriters, transacting 85 percent of the workmen's compensation insurance business written by bureau members, has organized the Assigned Risk Pool * * *.

Although membership is restricted to member stock companies of the National Bureau, the pool is not a bureau enterprise. Management and control will be under the direction of a board of seven governors * * *.

According to its articles of agreement, the pool was established to protect member companies from extraordinary hazards involved in carrying compensation risks assigned to them by State authorities under provisions of voluntary plans for assignment of otherwise uninsurable risks. Hereafter any such risks assigned and accepted by members of the pool will be reinsured among member companies (400).

Insurance by State in Peril

California's compensation insurance structure has been placed in jeopardy through the invoking of a supreme-court decision, dormant since it was handed down in 1933, State insurance officials believed today.

The decision holds that compensation can be claimed whenever an accredited doctor diagnoses an ailment as due to previous employment of the patient. Under previous interpretations of the law, claims could not be filed after 6 months for injury or disease or after a year for a death benefit.

Attorney for the _____ Miners' Union invoked the decision 2 months ago when he filed the first of 60 claims. He has since said he will file 250 more.

A reserve of $3,500,000 would be required to satisfy these claims, Timothy A. Reardon, director of industrial relations, said. At present the reserve is $1,000,000 for all claims (401).

The seriousness of the silicosis situation from the standpoint of the insurance companies is indicated by the statement by Dick (402) that "in the State of Illinois today there are pending suits which if rendered in favor of the claimants will bankrupt several insurance companies. It matters not", he said, "judging from a few of the verdicts rendered, whether the disease be tuberculosis or bronchial asthma, if it be termed 'silicosis' the jury renders a verdict in favor of the employee despite the sworn testimony of known reputable clinicians or radiologists." Kreuscher (403) stated that he understood that one insurance company in Illinois had silicosis suits amounting to almost $500,000 and that there are pending in the United States suits aggregating $2,000,000 on the subject of silicosis alone. Sappington (404) found that his estimate of a year ago of about $35,000,000 in silicosis claims pending had increased until today it was $100,000,000, an increase in 1 year of approximately 200 percent.

According to an editorial in Pit and Quarry, March 1935 (405), it is but natural that so profitable a field as the exploitation of the fears of business men through the filing of damage suits alleging disease on the part of workmen employed in hazardous occupations should have attracted unscrupulous lawyers; it is also natural that most damage suits alleging contraction of silicosis or pneumoconiosis during employment should be looked upon by actual and potential defendants as attempts to extort money on spurious claims. The editorial, however, calls attention to the fact that there are genuine cases of both diseases initiated and developed as the result of employment in or near lung-destroying dust -- in truth many of them. Their number has increased alarmingly in recent years, and unless something is done by way of prevention they may become a very serious financial burden to industry. The following statement by the author of the editorial indicates his attitude toward the dust situation:

> The situation cannot be met in anything but an attitude of expediency and self-deception, if industrialists adhere to the thought that all, or even most of, such claims are spurious. The situation is one that must be faced by recognizing, first, that both diseases exist; secondly, that they are caused and aggravated by the presence of siliceous and other dangerous dusts; thirdly, that the employer is responsible for the damage resulting to employees working in or around such dusts; and, lastly, that there are means by which the dangers of exposure, disease, and the resulting litigation can be greatly reduced.
>
> The first two points are matters of fact which it is folly to deny, however great may be the number of ill-founded damage suits; their recognition requires a change of attitude on the part of many employers. The third factor is only too well-known to those who have been forced to defend themselves in silicosis suits, whether these were based on facts or misrepresentations. The point mentioned last -- namely, that there are means for lessening the hazards of silicosis and pneumoconiosis -- is the one to which we direct the attention of employers.

On previous occasions we have said that the prevention of suits for alleged silicosis damage is more a matter of mechanics than of legislation -- for some have sought the passage of laws relieving the employer from liability in silicosis cases. The installation of modern dust-collecting equipment, of which there are numerous efficient examples on the market, is the most effective means of stopping the growing number of silicosis damage suits. The use of such appliances reduces the exposure hazards, not perhaps to the minimum (which is a term of perfection and therefore unattainable), but at least to the point where it becomes extremely difficult, if not almost impossible, for a worker to contract the disease. In the few cases where the disease may develop the employer when sued can point to his equipment as evidence of his desire to prevent, as far as technological development has made possible, the contraction of the disease by his employees. No more formidable disproof of alleged contributory negligence on his part could be set up; certainly there could be no more effective evidence of his interest in his employees' welfare for presentation to a jury.

We again urge upon employers the wisdom of studying this problem intently in cases where the danger is present and of examining all available mechanical means for stopping silicosis litigation before the foundation of a claim is laid.

In introducing an article entitled "Plain Facts About Silicosis and Its Hazards to the Rock Products Industries", which appeared in the May 1935 issue of Rock Products, the editor (406) stated:

> Producers in this section (Illinois), naturally, have been victims of racketeering lawsuits, but on the other hand there have been, of course, authentic cases of silicosis. Here silicosis is a common topic of discussion; even the most poorly educated workmen and the children know something about it. The producers are anxious to do everything possible to protect their workmen from any hazard for every reason, humanitarian as well as economic.

The article mentioned above urges (406) every employer in the rock-products industry to acquire a general working knowledge of silicosis and the accompanying hazards, whether or not he believes the contraction of silicosis by his employees to be an actual possibility. It points out that some 86 industries working in dust of one kind or another are genuinely alarmed because suits are now pending against them with damage claims aggregating more than $50,000,000. The fact that there are no reasonable grounds for many of these suits does not alter the fact that they are a real menace and may be won by the plaintiffs unless intelligently defended. The present plague of silicosis damage suits in the dusty industries does not mean that silicosis has suddenly grown more prevalent or that its effects are more apparent. It is believed that few such suits would have been filed had not the depression closed factories and thrown men out of work; defendant employers have stated that most of the pending suits against them would be dropped if they could offer employment to the plaintiffs.

An editorial on silicosis in the Mining and Contracting Review (407), April 30, 1935, states that both the real silicosis cases and the fake racketeers are serious problems to employers of labor and that those who doubt this had best investigate.

The following statement regarding the menace of dust appeared on the front cover page of the April 1935 issue of the Aerologist (408):

> Astronomers used to tell us that the earth was slowly losing its heat, and in a few million years it would become cold and life extinct.
>
> Entomologists state that insect life is increasing rapidly, and the time will come when devouring hordes of things that fly, and creep, and crawl will devour the earth.
>
> We recall, however, that ancient cities and civilizations that have disappeared from the face of the earth can usually be found, if we dig deep enough in the accumulating dust of the ages.
>
> Expanding civilization, developing industry, disappearing forests, bring more wind and less rain, more frequent and more serious droughts, and dust storms that have become much more than a nuisance.
>
> Dust is the menace of civilization.

The following excellent summary of the dust situation is quoted from the March 14, 1935, issue of Engineering News-Record (409):

> The Menace of Silicosis
>
> Growing concern about the insidious rock-dust disease, silicosis, has progressively brought about a situation in which ignorance, weak efforts at control, and the threatening complication of racketeering combine to bedevil both industry and worker. Each day the situation grows worse, and it is high time that it be dealt with by determined action.
>
> Recent news reports carry significant information about silicosis damage suits. In Missouri an aroused mining industry has just obtained a number of grand-jury indictments against two lawyers active in silicosis cases on charges of barratry (inciting of lawsuits). A Missouri lime company is seeking receivership to protect its assets against silicosis judgments. A mine worker's union in Butte has petitioned the U.S. Senate for a sweeping investigation of the dust hazard in mines. And in the field of construction an able and reputable contractor is starting his third campaign of defense against a multitude of suits arising out of the driving of a 3-mile tunnel in West Virginia.

Industry's bewildered, helpless, and planless attitude toward silicosis is aggravated by scientific ignorance. Experts who have studied the disease for years agree only in recognizing that the hazard exists. Industry thus is faced with several major problems, chief among them knowledge of cause, development of effective means of prevention, and detection of the conditions that favor silicosis.

As to diagnosis and knowledge of cause, medical ignorance is great. Most authorities hold that silicosis is a fibrosis of the lungs caused by exposure to dusts containing high concentrations of free silica particles less than 10 microns in size. But a British geologist claims that the cause is not silica but sericite, a fibrous mineral of the muscovite family. Other authorities regard all dusts as potentially harmful. Some claim that silicosis cannot develop in a normal lung free of other infection, such as tuberculosis. There is disagreement as to the length of exposure required to contract the disease and the time required for its development. The U.S. Public Health Service states that there is danger in any atmosphere that contains more than 5,000,000 of the fine silica particles per cubic foot. And finally, medical experts claim that few doctors are capable of diagnosing silicosis.

Prevention is a field of even greater ignorance. Meetings called to consider methods of protecting rock workers almost uniformly fail to bring out definite proposals, and when some device or method is suggested by one speaker it is promptly condemned by another.

If rock dust causes silicosis, effective control of such dust should give protection. But what form of control? Thorough ventilation is advocated, but the first silicosis suits in construction come from an amply ventilated tunnel job. Free use of water is advised -- wet-drilling, spraying, and the like. Yet in the Rand mines in South Africa, where such measures are in common use, silicosis is rampant. Control of the drill dust at the drill hole is recommended, but there is no apparatus for this purpose in commercial production today, and even if it were available and effective it would still leave the dust created by blasting, mucking, and other rock-removal operations uncontrolled. Perhaps a solution is offered by the stringent specifications for respirators recently drafted by the Bureau of Mines and successfully met by three manufacturers. Respirators have so long been considered useless that the development of an effective mask is encouraging.

It may be that no single preventive measure is sufficient, and that a combination of two or more will be required. Here, however, we have the third problem. How can a contractor, for example, determine whether his work involves silicosis-dangerous dusts, or whether the kind and amount of dust is such as to expose workmen to the disease? No simple method of analysis is available. Before we can get far in the silicosis fight such methods must be developed.

A final problem is that of compensation laws. Four States now include silicosis in blanket industrial-disease clauses in their compensation acts. Two other States have special insurance funds to which employers may voluntarily subscribe for protection against silicosis suits. In several States legislatures are now considering silicosis compensation acts. Yet no single silicosis compensation act so far passed or proposed provides fair protection of labor and industry alike. Insurance executives warn that industry should avoid the delusion that the silicosis problem can be solved by insurance except at a very heavy cost. And most troublesome of all is the fact that silicosis develops so slowly -- often after many years, apparently -- as to make it almost impossible to determine responsibility with sureness.

This brief summary reveals the gravity and the magnitude of the situation. The problem is too big for any one individual or firm, even for a single group or industry. It demands the attention of a national organization. Perhaps the Bureau of Mines, if given adequate funds for thorough investigation, could show the way to a solution. The present uncoordinated activities of industrial hygienists, public-health authorities, labor, law-making bodies, and industries themselves are bringing no results. Coordinated and ably directed, however, they are certain to move foreward toward a solution of the problem.

Section 2.- Legal Aspects of the Dust-Disease Problem

Those interested do not agree that inclusion of dust diseases in compensation schemes for occupational diseases would solve the problem. McCann (395) believes that the movement to include pneumoconiosis in the workmen's compensation law should not be hastened, although ultimately this will be desirable; that it would be better to await the outcome of the common-law actions now pending as medical opinion and legal precedents may be established which will be favorable to the employer in regard to the contributory effects of dust upon nontuberculous respiratory infections; and that if a retreat to workmen's compensation is forced an effort should be made to adhere as closely as possible to injuries or diseases that can be defined specifically, although this may leave some opportunities open for common-law actions. However, such a course would be more advisable than an attempt at blanket coverage, the cost of which would be ruinous to industry. He also states that if the racketeers are successful in winning suits in cases of infectious injuries to lungs and upper air passages the result will be complete chaos in the insurance field; even if the cases are restricted to recovery for pneumoconiosis the tribute levied from industry will be "colossal", and whether paid through common-law action or through compensation it will be "a burden too heavy for some industries to stagger under." He feels sure that the cost of eliminating dust will be far less than the cost of insuring against the hazards of dust and suggests that specific provision be included to adjust compensation to degree of disability and thus eliminate most spurious claims.

Kellogg (410) states that the common law is not well-adapted to the determination of liability for silicosis; merely to put silicosis under the workmen's compensation act will not give the employee a quick and sure remedy at a reasonable cost, nor will such procedure bring within reasonable bounds the expenditures of the employer. In procedure under the common law three points must be established:

1. Has the plaintiff contracted silicosis. This is almost purely a medical question.

2. If the plaintiff has contracted silicosis, did he contract it because of conditions in the defendant's plant. This is partly a medical and partly a nonmedical question. Whether the conditions, having been once determined, were such that they probably caused silicosis is a medical question.

3. The remaining point to be proved by the plaintiff in a common-law action is whether the defendant was negligent in permitting the conditions which caused the injury to the plaintiff by silicosis. This question is a question of ordinary law and fact. It involves practically no medical questions.

As Kellogg (410) points out, the employee's remedy by common-law action is slow, difficult, and extremely expensive to both employee and employer; moreover a just and satisfactory outcome to either is uncertain. Although inclusion of silicosis in the workmen's compensation act would remove from consideration determination of questions of negligence, it would not remove the question as to where and in whose employ the workman inhaled the injurious dust; nor would it solve the medical questions of diagnosis and prognosis.

According to Tillson (411) "we in the United States have been too slow to realize the social and economic need for placing the dust hazards in industry under the jurisdiction of compensation laws, and it is to our shame that we have waited until forced by the economic pressure of 'racketeers' into a situation where we welcome such laws for our own self-protection." However, he thinks that the more hazardous trades will have to be very profitable to withstand the overhead involved in the heavy compensation expenses or the costs and awards of lawsuits resulting from an awakened public consciousness that the fruits of industry must not be enjoyed at the expense of the health and safety of the labor that produces them. In answer to the question, "Why advocate compensation laws in industry?" Tillson (411) states:

> Because when such laws are fairly, clearly, and intelligently drawn they give most necessary protection to both the worker and his employer from unscrupulous interests who prey upon both. The worker is seldom familiar with all of the hazards of his occupation unless they are specifically pointed out to him. He has a fear of the expense of time and money, and the uncertainty of results, from participation as a principal in lawsuits. His savings from wages

can never compensate any incapacity and subsequent loss of earning power from industrial hazards, so he and his dependents are not provided for in case of such a misfortune contingent to industry; therefore he needs the protective interest of some well-informed and unbiased body politic.

The employer cannot be both a specialist in his own art and also qualify as a skilled pathologist and hygienist. He, too, needs guidance in the matter of vocational hazards as a result of expensive research beyond his means, and therefore dependent upon group activity or some public agency, in order that he may care for and protect his workers in a manner that any fair-minded employer desires. But without regulations and compensations prescribed by law he does not know what he should do and is left subject to disastrous monetary judgments in suits at common law from illinformed or misinformed judges and juries who cannot be expected to learn in a few days the technical intricacies to which technical experts have devoted years of study and which can be solved by them only after long periods of special experience. So without compensation laws the employer is subjected to the preying of "shyster" lawyers who exact from the worker a fee of usually one third to one half of the judgment granted to him and have even obtained as much as 80 percent of the amount allotted. Usually there is no limit to the amount which can be recovered, but a few States have enacted a statutory limit on recoveries for death. The judgment at common law is in a lump sum and is final after the defendant has failed in his appeal to the court of last resort; and such a judgment is not subsequently subject to revision even though newly discovered evidence proves that the condition of the plaintiff was exaggerated at the trial.

Under most compensation acts the payments are made in installments and even after the trial are subject to revision on the basis of additional evidence of the physical condition of the claimant, because the latter is still subservient to the powers of the compensation board. The employer, by the provision of liability insurance in accordance with compensation laws, can budget his vocational hazards and thereby avoid such uncertainties in his business, and he is taught the economic value of preventive measures and is justified in applying them.

Unscrupulous lawyers and doctors are deterred by compensation laws from preying upon both labor and capital.

Leland (412) points out that workmen's compensation legislation almost invariably has been a forerunner of general sickness insurance. In 1910 no State had such legislation. Today all but four have more or less elaborate systems of protection. There is no agitation for their repeal and little opposition to their continual extension. Extension, according to Leland (412), has already made "occupational disease" compensable in several States, and more are added annually. He quotes from a report of the Industrial Commission of South Dakota:

The original idea of workmen's compensation law was that of helping the injured worker to bridge over his troubles until he was again able to resume his ordinary labor. But by actions of legislatures, courts, and commissions it is beginning to approach that of a general plan of health and accident insurance.

However, the extension of compensation of industrial accidents to cover occupational diseases has proceeded slowly, although according to Ainsworth (413) there is no fundamental difference between them; both relate to prevention of injury to industrial workers -- the one from physical violence, the other through impairment of health. The two earliest laws (Switzerland, 1877, and Germany, 1883) covering employers' liability for industrial accidents provided also for the inclusion of occupational diseases (414). This seemingly logical interpretation of the scope of workmen's compensation laws to include industrial diseases within the meaning of the law was later discarded probably because of the difficulty of determining with accuracy the causal connection between diseases of gradual onset and slow development and the occupation of the victim. Disability to work is the only legal manifestation of occupational injury, and disability from disease often does not ensue for months or even years. By the time disability is established the diagnosis of its causes may be obscured, and the workman affected may have changed occupation or employer several times (414). The Committee on Standard Practices for Compensation in Occupational Disease of the American Public Health Association (414) gives the following reasons for the exclusion of occupational diseases from compensation:

> The state of medical knowledge has not yet reached a point where definite rules can be laid down for the differentiation of all diseases and their complications and sequelae which may arise from the conditions under which a man works, much less for the extent or duration of the disability which may fairly be claimed to follow upon them. Accidental industrial injuries have been to a certain extent clarified and classified, and standards for their diagnosis, treatment, and consequent loss of working time have been built up from the experience attendant upon the passage of compensation laws, however, and it would seem as though the time had arrived when, in view of recent intensive scientific study which has been given to occupational disease, something of the same sort should be attempted at least for the industrial diseases now covered by the various laws. Such standards could not, of course, be included formally in any law, but would be exceedingly useful as a guide to both the medical profession and to laymen concerned in the adjustment of compensation cases.
>
> Fears concerning the wide open door through which the employer might seem to be held liable for all ill-health among his workmen regardless of its origin, on the claim that it had been "aggravated" by the nature of their work, are by no means groundless, and the business of deciding whether a man's occupation has lighted up, accelerated, or exacerbated a previously existing disease is a source of the greatest confusion and bewilderment in workmen's compensation courts. The

settlement of straight out-and-out occupational-disease claims has become a minor portion of the question. That other objections to the inclusion of occupational diseases in these laws have been overcome or proved more or less groundless will be seen in the following review of the laws. It will also be seen that under those laws which do not expressly state their intent on the subject the question of whether or not diseases are to be included and, if so, what diseases and when has often held a place in the foreground among the controversial aspects of the law.

Some of the State laws in the United States, for instance, still provide fertile ground for dispute over the construction that is to be placed on the words "injury" or "personal injury" where they are unqualified by the word "accidental" in the act. In a number of cases, this type of act has been interpreted, not without prolonged debate, to mean that diseases of occupational origin may be included. Generally speaking, when the words "accidental" or "by accident" are used in the act, it has been decided that those suffering from occupational diseases have no claim to compensation unless occupational disease has been specifically included in addition. Nevertheless, certain diseases which may occur with practically the same suddenness as an accident, such as gassings, have been impossible to exclude, and quite a varied collection of diseases has always been included if it could be shown they had resulted, even remotely, from an accidental injury.

This committee (414) roughly classifies most of the forms of workmen's compensation acts at present in effect as follows:

1. Laws which definitely include occupational diseases.

   A. Those having a schedule naming the diseases which are compensable.

   B. Those having a schedule naming diseases which are compensable only if they occur in workers engaged in certain listed industrial processes.

   C. Those having no schedule of diseases or processes.

2. Laws which do not specify coverage for occupational diseases but the wording of which is such as to allow legal interpretation to the effect that diseases arising out of and in the course of employment are compensable in the same manner as industrial accidents.

3. Laws which definitely exclude diseases except those which result from an accidental injury.

In scoring the "miserable lack of human concern" manifested on the part of the majority of States and those interests that sponsor legislative thinking in the compensation field Wilcox (415) states that the most cruel defect is the complete absence from every schedule list of those diseases of the lungs or respiratory tracts produced by that "most pronounced health hazard known to industry -- dust." He claims that the writers of the schedules knew all about silicosis and did not omit through oversight; that "they were willing that men should give their lives to sand-blasting, and to chipping, cutting, grinding, and polishing operations of the metal and granite industries; that they were willing to leave these men and their families to bear the most dreadful ending that may come to a laborer."

The report of the Planning Committee for Mineral Policy of the National Resources Board (416) calls attention to dust disease as the greatest health menace to the miner, whether in coal or in metal mines. It states that more underground workers probably are incapacitated or die from breathing excessive amounts of dust than are killed by mine explosions and fires and that while health is the greatest asset of any human being it is of greater relative value to the miner because his occupation demands the possession of far more than ordinary endurance and command of faculties. Yet silicosis is not included in the compensation acts of most of the States of the United States.

Sayer (417) places dust diseases in a class by themselves because they call for special treatment and rules in the consideration of claims; the subject is highly technical and presents many difficulties. He calls attention to the generally accepted fact that there are thousands of workers in inorganic dust whose lungs are affected to some extent by silicosis but that all of these cannot be put out of the industries in which they are employed and industry cannot possibly pay the huge sums in the aggregate that would be demanded if the law suddenly recognized that all these workers should be compensated in money — not for what might develop but for the exposure already incurred over past years. To attempt to saddle such a load on industry would swamp it beyond the hope of recovery -- the economic effects would be most disastrous. With regard to a compensation law for silicosis he states:

> The only way industry can avoid this crushing burden is to see to it, insistently so, that the legislatures do not enact all-inclusive occupational-disease laws in broad general terms. The only safe and scientific way is to insist that where occupational diseases are to be included in the law it should be done in the definite scientific way by including all diseases known to be peculiar to the occupations in a schedule or list contained within the law itself. It is then a perfectly simple matter, as new processes develop new types of disease, and they can be medically and scientifically described and recognized, to include them as additions to the schedule, as has already been done in some States.

A model law for silicosis must contain many detail provisions other and different from the provisions for occupational diseases

generally. It must make provision for recognizing the various stages of the disease, for periodic medical examinations, by X-ray and otherwise, to detect the earliest beginnings of the disease, and the steps to be taken when the presence of the disease is recognized. Also provisions must practically be made for a gradual assumption of the liabilities, so that the already accumulated cases are not at one time loaded on the industry, creating a burden impossible of assumption.

Industry does not object to the inclusion of such conditions in the law in a practical way. It recognizes the obligation to compensate for silicosis and asbestosis. It will take the burden so far as it practically may, doing justice to the worker and preserving the industry upon which the worker is dependent.

The foregoing facts will illustrate in a brief way the utter necessity for sane thinking and practical approach to this very complicated and difficult problem. If we would do only lip service to labor, we would say give us an all-inclusive occupational-disease law. If we would do a real and lasting benefit to labor, we will courageously meet a baffling situation with a practical remedy, we will make difficult the exploitation of labor by racketeers, and we will be enacting a schedule law for occupational diseases reach all real situations and at the same time permit industry to survive.

According to McLeod (418) the owner of an industry wherein the man-made dust hazard pneumoconiosis is evident has more and more to worry about every day, especially if his dust is a silica dust and his plant happens to be in a State where compensation laws do not recognize silicosis as a compensable occupational disease. On the one hand, the dust hazard menaces the health and future welfare of his workers; on the other, he unfortunately is open to damage suits at common law which jeopardize the existence of his industry; and, lastly, the insurance carrier, who heretofore has accepted the liability of coverage for such pneumoconiosis in good faith, now is misconstruing one or two clauses in his standard policy to dodge the liability. McLeod (418) also points out that the absence of regulations regarding dust hazards has led the industries to neglect dust control or dust prevention. At present the quarry owner is practically "on the spot" if his dust is silica, and the insurance carrier is attempting rather successfully to deny the liability on his part of the insurance contract. In answer to the question, "What can be done about it?" he states:

> The employee must be protected. The owner must be protected by his dust hazard being recognized as an occupational disease, compensable by the State compensation laws.
>
> Opinion must be solidified among all industries having a silicosis hazard, whereby pressure must be brought to bear to force enactment of proper legislation to place economic responsibility for this condition. * * *.

After years of experience as both a mine operator and a quarry operator the author cannot agree with the opinion that some dusts are harmless and even beneficial. Any dust, especially silica, once entered into the lungs is damaging, and the sooner the industry recognizes this fact instead of avoiding it like the proverbial politician's "hot poker", the sooner will the industry become straightened out as regards dust control, allowable dust count, recognition of silicosis by State compensation laws, rerating of the hazard and the standing of the carrier.

The operator, too, has a moral responsibility toward his employers and the rising standard of education in making the worker sit up and take more notice that he might become a silicotic.

Dust, like the poor, we will always have with us to some extent in the industry, and it is the duty of the operator to minimize it, just as it is the duty of the State to insist on its being minimized or eliminated.

There is a great field for research for the engineer to fight this hazard, and it will be eventually eliminated or cut to a minimum. But, in the meantime, the owner must be protected from the carrier.

Lazenby (419) warns the employer not to underestimate the danger to which he is exposed in the present trend toward the liberalization of existing workmen's compensation laws to include occupational disease. Already the existence of several industrial concerns is threatened by litigation arising from silicosis. The money involved runs into millions of dollars, and the surface has not been scratched. In addition to the possibility of legitimate claims the rackets have already invaded the occupational-disease field, and unscrupulous lawyers aided by unscrupulous or uninformed doctors are fabricating claims on a wholesale basis. The employer will be forced to pay this bill as well as bills for many diseases not heretofore recognized as having industrial origin but which later, as interest and research develop, may prove to be so associated in their inception. The employer must either be willing to pay this cost, or he must make an effort to prevent it. According to Lazenby (419) one of the chief obstacles that the safety engineer of the casualty company meets in the industrial plant is the resistance of the management to changes in methods or safeguards to prevent accidents. If this resistance is as stubborn in the field of occupational-disease prevention as it has proved to be in accident prevention the employer will find his costs for insurance prohibitive, or he may even find himself uninsurable. The employer is advised to familiarize himself with any legislation proposed for inclusion in the workmen's compensation act provisions embracing occupational disease. Such laws, unless rigidly drawn, can open avenues that will impose a tremendous and unjustified drain upon industry as now conducted. Admitting the justice of the philosophy that human wear and tear is as proper a charge against industry as the wear and tear of machines, Lazenby (419) states that the administration of some of our workmen's compensation acts has been so

broad and liberal that industry has been taxed far beyond the spirit of the law and the requirements of social justice. He warns that occupational-disease legislation, unless carefully drawn, is even more susceptible to broad interpretation than workmen's compensation laws. It can be adapted easily to embrace in effect compulsory health insurance, old-age pensions, and unemployment insurance for workers. There are many advocates of the theory that occupation can be considered the basis for almost any disease to which mankind is heir, and there are many theorists who believe that capital should bear all the burdens of labor and are eager for the opportunity which occupational disease seems to offer to put their theories into practice.

The following quotation from an article by Tillson (420) gives the viewpoint of some of the workers and indicates the rising interest of the laborer in an intelligent consideration of his working conditions; whether or not his viewpoint is correct it must be accepted by industry for correction of conditions or misunderstandings:

> The mine officials here have long been aware of the dangers of dust but have never made more than a half-hearted effort to abate the hazard. The more intelligent miners have always wet down their places and advised their fellows to do the same, but there never has been a systematic campaign to educate the miners about the dust hazard. This is one of the things our union hopes to bring about in connection with our effort to get silicosis legislation.
>
> We have already realized that it will be difficult for us to obtain far-reaching social legislation with the present political set-up of this State * * *. The last legislature was largely controlled by the mining and utility companies, and so we are laying the groundwork of a movement by which we hope to unite the workers and farmers behind a common program beneficial to both classes * * *. There are several hundred old-time miners who are still able to do a day's work and make a living. It is possible, if they are covered by the law and the law should pass, that they would immediately be X-rayed and cut off the pay roll. Then we have the same situation referred to in your second article -- miners who have worked in every mining company in the West. We could not expect the local companies to compensate these men for a disease contracted under other employers.
>
> Of course it has already become apparent to me that silicosis legislation is a problem too difficult and complex for ordinary miners to cope with by themselves, but we are convinced that a start must be made some time. If nothing else, we will drag the subject of dust disease out into the open and give it the publicity it deserves. I believe that there has been a studied effort here in _____ to minimize the importance of silicosis. If a miner dies from tuberculosis complicated with silicosis the disease is never mentioned in the press. They call it a "long illness."

We visited the _____ tuberculosis sanitarium about 2 weeks ago and got some interesting figures. For the 5-year period 1929-33 there were 179 men admitted from _____ County, and, of these, 151 miners, 80 percent of the population of the county, are concentrated in this mining camp. The adult population is about 20,000, but during the period mentioned the actual underground workers did not exceed 4,000. During 1932-33, 27 men from this county died at the sanatarium from tuberculosis, and 23 of these were local miners. Nearly every miner's case was combined with silicosis. * * *.

In considering methods of defense against silicosis suits most authors emphasize the importance of preventive measures. According to Sappington (421) progressive industries will avail themselves of preventive methods and will discover the difference not only in economic cost but also in lessened absenteeism, labor turn-over, inefficiency, spoilage, and other factors so intangibly represented by a dollars-and-cents point of view. Furthermore, the relative value of knowing qualitatively and quantitatively the degree of health hazard in any given industrial environment is greatly enhanced by having such information before differences of opinion arise as to what constitutes a hazard.

The following statement by Farrell (422) indicates the defensive value of preventive measures:

It is entirely possible to work out a defense to silicosis cases for claims arising in the future if all the statutory requirements are complied with in the various plants and if it can be shown that the employer has done everything possible to safeguard his employees.

All the law requires is that the employer exercise ordinary care and caution.

This, of course, implies that the employer must comply with statutory requirements with reference to his plant and property; and where there is a violation of any statute regulating the operation of any plant or factory, such proof on the part of the plaintiff is sufficient to take the case to the jury, and all that is necessary is to prove the disability with medical evidence.

Even though an employer complies fully with a statute, it is sometimes shown in these cases that the contrivances used in such compliance are defective or are not used continually. This, of course, makes out a case of negligence.

The following opinion filed on the appeal of the Pennsylvania Pulverizing Co. (423) from the decision of a lower court in a lawsuit in which an employee claimed to have contracted silicosis illustrates the value to the employer of taking measures to protect his employees from occupational-disease hazards:

In the United States Circuit Court of Appeals for the Third Circuit (No. 4861; Term 1932)--Pennsylvania Pulverizing Co., Codefendant-Appellant, vs. Eldred C. Butler, Plaintiff-Appelee

Appeal from the District Court of the United States for the District of New Jersey. Opinion filed September 29, 1932, before Buffington, Wooley, and Thompson, Circuit Judges. Wooley, Circuit Judge.

Pennsylvania Pulverizing Co. is engaged in the business of grading and pulverizing sand for commercial purposes. The process, shortly stated, is to dig from a pit free silica sand such as is found on beaches by the sea. A portion of this raw produce is sold for building purposes and for use by railroad locomotives and foundries. For practically all other purposes the sand must be converted into its relatively pure crystalline form; therefore the balance is washed over concentrating tables to eliminate fine particles and impurities. The residue, now pure silica but with quartz particles of different sizes, is, after drying, hoisted in conveyor buckets to the top of an 80-foot tower and dropped on a vibrating screen of a certain mesh. Sand grains which are too large to go through the screen are carried off as tailings; the sand which goes through the first screen but does not go through screens of progressively finer mesh positioned below is sold mainly for the manufacture of glass. That which is not so disposed of is put through airtight revolving pebble mills and ground to a powder which, after sale, usually is used for the abrading element in many commercial products, among them tooth paste. Although much of the sand movement is in airtight passages, the operations as a whole are very dusty.

Eldred C. Butler had for nearly 2 years been an employee of the Pulverizing Co. He claimed that, while in its service, he contracted a disease, or perhaps because of uncertainty of the medical profession the ailment may be called a condition, known as silicosis. However termed, it is serious. It arises from exposure to silica dust and is incurable. The symptoms are shortness of breath, limitation of lung and chest expansion, loss of weight, and a dry cough. When silica dust is inhaled, the particles under 10 microns in diameter (a micron is 1/25,000 inch) enter the tiny lung sacs and stay there, setting up an overproduction of fibrosis or scar tissue. These small dust particles do the mischief; the larger or ordinary dust particles are discharged by the respiratory organs.

Stating the duties which in law a master owes his servant and averring that by breach thereof he had, on inhaling uncontrolled silica dust, sustained serious injuries, Butler brought this suit. He specified, very satisfactorily from a pleader's standpoint, four grounds of negligence which we shall state and discuss presently. From a judgment in his favor, the defendant took this appeal.

We must, preliminarily, dissipate the atmosphere which beclouds the real issue of the case in order to bring them sharply into view. The plaintiff, at the argument, laid great stress upon the dusty character of the industry in which the defendant is engaged, indicating that it is highly dangerous in that it involves serious and somewhat insidious hazards to health, and implying, without asserting, that the industry is unlawful. Assuming for present purposes that the industry is a dangerous one, yet, even so, there is no evidence that it is unlawful. Like many industries whose products are pulverized materials, such as cement, lime, gypsum, feldspar, barytes, talcum, snuff, and medicinal and dental bases which affect the health or comfort of their operatives, the product of the industry in which the defendant is engaged is impalpable powder -- indeed, its product is dust, the manufacture of which is not _per se_ unlawful and the operations are not _per se_ negligent. Therefore, whether this is an industry which, on public or humane grounds, should be abolished is a matter not to be determined by the judicial department of the government and is not here in issue.

There are many questions raised on this appeal. The main and perhaps controlling one is whether the trial court erred in refusing the defendant's motion for a directed verdict for one or more of the reasons there alleged. The first reason was that there is no proof of any one of the four grounds of negligence on the part of the defendant which the plaintiff alleged in his complaint and on which he built his case.

The first ground of negligence charged, and assailed as not proved, is (_a_) that the defendant failed "to use reasonable care to provide the plaintiff with a reasonably safe place to work."

The duty of a master in that regard is, as matter of law, so well established that it does not call for discussion. (_Burhs_ v. _Del. & Atl. Tele. Co._, 70 N.J.L. 745.) This averment, however, is general and may be passed by in view of the particular averment to the same effect and to which all evidence on the point was directed, that (_c_) the defendant, in making the place safe for the plaintiff to work, failed "to use reasonable care to provide a proper ventilating system in its plants."

The Pulverizing Co. had been in the business of pulverizing sand since 1906. In 1929 it built a new plant at Toms River, N.J. Before completing construction, its president, who had long been conversant with the industry and its objectionable operative features, took certain measures bearing on a master's duty to protect his servants by exercise of reasonable care, to which he testified as follows:

"When we were drawing the plans for this plant * * * at Toms River, both myself and several of our engineers visited a great many dusty plants all over the eastern part of the United States. By that I mean east of the Mississippi River. I went as far as St. Louis to see one.

I inspected plants in Cleveland and Rochester, in Keene, N.H., down at Erwin and Sweet Water, Tenn., all plants I could find where they were handling dusty material, in order to benefit by all of their experience in securing the very best dust-collecting and ventilating system that was possible to get for that plant at Toms River. They submitted plans for that dust-collecting and ventilating system. We adopted those plans and instructed them to go ahead. Those plans were submitted to the Department of Labor at Trenton, Department of Labor of the State of New Jersey, and that ventilating and dust-collecting system covered the entire plant where there was any dust at all. It did not apply to parts of the plant where there was no dust.

"We selected the Northern Blower Co. because we found they had done a great deal of the work outfitting other plants in the other dusty trades, not only the silica business but in a great many others, lime and gypsum, feldspar, etc. We found they had a great deal of experience, and we believed their system was the best system we could obtain for that purpose.

"We installed that completely; the cost of it was pretty heavy, but we installed it as planned, at the start, before the mill was finished. That was fully installed with the working of the mill."

Professor Drinker, associate professor of hygiene at Harvard University, School of Public Health, testifying with reference to the defendant's ventilating system, said, in answer to a question whether or not it was standard in that type of plant: "There is not any real standard. It is fully in keeping with, if not better, than the standards in other plants that I saw or in grinding plants in general."

M. E. Eiben, president of the Northern Blower Co., Cleveland, Ohio, which designed and installed dust-collecting systems all over this country and in foreign countries; indeed, he had made dust collecting his life's work and had done nothing else. He further testified that the dust-collecting machine in use at Toms River is of the type approved by the State of New York and is accompanied by certain guarantees as to clean discharge of air. When asked whether or not the equipment which his concern had installed compares in efficiency with dust-arresting and dust-collecting devices in other silica plants, he answered that it does. To the question: "And is it abreast of the art?" He replied: "It is up to the minute."

Ellwood Driver, inspector of the New Jersey Labor Department, testified that in December 1930, he visited the plant twice and found it "in excellent condition" and on examining the ventilating apparatus, he found it "fine * * * good, very good."

Dr. Andrew F. McBride, former Commissioner of Labor of the State of New Jersey, visited the plant in May 1931. Though after the event,

his testimony was admitted on a promise by the counsel to connect it up. It was to the effect that, as to the condition of the plant with respect to safety appliances and precautions taken for health of the workers, he "found it to be in a very good condition."

John Roach, Deputy Commissioner of Labor of the State of New Jersey, examined the plant in December 1930 and January 1931. In reply to a question with reference to safety appliances, both ventilators and respirators, he said: "I found it satisfactory."

Morton I. Dorfan, manager of the dust-collecting division of the Pangborn Corporation, a member of the National Safety Council on the Sand-blast Hazard Committee of that organization, visited the plant in May 1931. On being asked to tell the court and jury the condition and efficiency of the ventilating system which he found there in operation, he answered, without objection: "I would consider that ventilating system, even though it has been built by a competitor of ours, as equal and possibly superior to many I have seen in plants, handling, first of all, the same kind of dust, and other siliceous dusts."

Dr. Henry H. Kessler, director of the State Occupational Disease Clinic of New Jersey, speaking with reference to the equipment for ventilation at the Toms River plant, said: "From my general knowledge of plants having dust hazards, I believe the equipment used was satisfactory for the purpose."

Opposed to this testimony for the defendant on the issue of negligence in ventilation, the plaintiff proceeded to prove negligence in this particular by testimony that his work about the plant was in sweeping up the dust, in bagging sand, sometimes directly from the end of the mill, in burlap, or tightly woven cloth bags which sometimes would burst, in working at the drier, but mainly (for about a year) in working in the screen tower keeping the vibrating screen from clogging by means of a compressed-air gun and a steel brush. Butler testified that to the screen at the top of the tower there ascended through an open shaft a belt conveyor with uncovered buckets of sand, and that, though from buckets and screen the dust was very bad, there was no ventilating system except windows which he was ordered "to keep shut, to keep the sand from blowing off from the belt, going to the screen." And, finally, that Driver and Roach, officials of the New Jersey Labor Department, recommended the use of paper bags in place of fabric bags.

On this evidence the court submitted the case and allowed the jury to find whether the defendant was negligent, because of lack of reasonable care in failing to install and maintain a proper ventilating system in its plant.

Whether on this evidence the court erred in submitting the case to the jury is a question to be determined not by weighing the

evidence for the plaintiff against the evidence for the defendant, since that is not the function of an appelate court, but by subjecting the evidence for the plaintiff alone to the test of several well-established rules of law relating to the quality of proof in general and to the character of proof required in this particular kind of negligence case. The first, which is negative, is that in Federal courts the scintilla rule no longer exists; the second, that evidence to be controlling should be substantial enough, if submitted, to sustain an affirmative finding by the jury (Evans v. Ely, 13 Fed. (2d) 62,64); and to be validly submitted it must be "something of substance and relevant consequence, and not vague, uncertain, or irrelevant matter not carrying the quality of proof." (Minahan v. Grand Trunk Railway Co., 138 Fed. 37.)

The plaintiff's evidence of the defendant's ventilating system might show negligence were it permissible to infer negligence from the fact of the plaintiff's injury, or it might show a spark of evidence of negligence from the fact that the windows in the tower were kept closed. But without more to prove that keeping the windows closed need not, in an orderly manufacturing process, have been done or should not, for the plaintiff's protection, have been done, that evidence, standing alone, is not enough to submit to the jury, or, if submitted, is not enough to sustain an affirmative finding of negligence. It left uncertain and unproved, and therefore left the jury of conjecture, whether the defendant did something it should not have done or failed to do something it should have done. Keeping in mind that the plaintiff charges the defendant with negligence, not in making too much dust or in making more dust than a properly organized plant properly operates would make, but in failing to use reasonable care to provide a proper ventilating system to control the dust it did make, proof of much dust at a particular place without proof that the defendant could and therefore should have provided efficient means to overcome it is not substantial enough to be controlling on the averment that it was negligent in failing "to use reasonable care to provide a proper ventilating system."

Moreover, the plaintiff's evidence of negligence in ventilation must respond to the test of another rule affecting a master's duty to his servant, which is that he is required only to use "reasonable care" in selecting instrumentalities for his protection. On this rule, now established almost everywhere, this court said in Haines v. Spencer (167 Fed. 266,271):

"The employer is not an insurer, and the duty imposed upon him is not to furnish the safest or newest and best machines and appliances, but only to exercise due care to provide those which are reasonably free from danger. (Citations.) And the rule as to this is the usage of the business, negligence not being imputable where the machine in question is that which is generally employed." (Citation.) (Tompkins v. Machine Co., 70 N.J.L. 330; Stapleton v. Reading Co., 27 Fed. (2d) 242.)

The court, continuing on the question as to how this is to be proved, said:

"It may be that, for the purpose of comparison, it would be admissible, in order to aid the jury in determining what is reasonably safe, to put other machines in evidence which are in common and ordinary use in similar establishments." (Citing authorities for and against this procedure.)

Without expressing ourselves upon the procedural part of the rule, it should be noted that, whatever it be, the plaintiff in this case, though recognizing the rule of "reasonable care", assailed the defendant's system of ventilation (as involving negligence) by proof of dust in large quantities here and there, not by proof of other mechanism or means known to the industry or to the science of hygiene by which the dust could be controlled more effectively. So the plaintiff's evidence not only failed to prove (by showing better instrumentalities) that the defendant's ventilating system might have been better but, for the same reason, it stopped short of proving it was not such a system as by the exercise of reasonable care could, and should, have been furnished. Failing affirmatively to meet this test and failing also to contradict the defendant's evidence as to its exercise of reasonable care in studying the dust problem, endeavoring to solve it, and providing not only "apparatus in common use" but "apparatus of superior quality", purchased from a reputable and experienced manufacturer (Bauman v. Condin, 75 N.J.L. 193, 195; 76 N.J.L. 575), the plaintiff's evidence was insubstantial within the rule of Evans vs. Ely, Supra, and offended the final rule (and test) which forbids the submission of such uncertain evidence from which the jury was permitted to guess and decide, against the practice of the industry and knowledge of the art, what is a proper or improper ventilating system in the industry. (Del. L. & W.R.R. Co. vs. Koske, 270 U.S.7; Kilpatrick vs. Choctaw O. & G.R. Co., 121 Fed. 11; Canadian Northern Railway Co. vs Walker, 172 Fed. 346; B. & O.R.R. Co. vs. Newell, 196 Fed. 866; Lehigh Valley R.R. Co. vs. Passinier, 4 Fed. (2d) 46.)

Another reason in the defendant's motion for a directed verdict (still under consideration) is that the plaintiff did not prove its second averment of negligence in that the defendant (b) failed "to use reasonable care to provide the plaintiff with proper masks or other appliances or safeguards in said work."

The president of the defendant company testified that before starting up the Toms River plant he gave a great deal of study to masks and particularly to the types made by the Willson Co. He visited concerns that purchased these masks, saw them in use in dusty plants, and then adopted them.

Dr. Andrew F. McBride, Commissioner of Labor of the State of New Jersey, testified that the masks with which the defendant supplied its servants "were practical and efficient."

John Roach, Deputy Commissioner of Labor of the State of New Jersey, testified that masks of the type in the defendant's plant had been approved by his department of labor for use in this type of work.

Harry F. Speer, president of the New Jersey Pulverizing Co., a competitor of the defendant, testified, as did one of the witnesses for the plaintiff, that "air-line masks", another type, were still in an experimental stage. He said that the masks used by the defendant were in his judgment, after 30 years' experience in the business, better suited for the purpose.

Dr. Fred Willson, president of the Willson Products Co., Reading, Pa., a member of the Sand-blast Committee of the National Safety Council and of the Advisory Committee of the Bureau of Standards, said with respect to the defendant's masks, that they are used generally in dusty trades and are "for all practical shop purposes fully protective." Speaking with reference to the air-line or direct-pressure masks, he testified: "To the best of my knowledge it had not been used and I would not have recommended it."

Professor Drinker, of the School of Public Health, Harvard University, said that the Willson sponge mask used by the defendant is "a little ahead of the standard" and the air-line mask, which is still in an experimental stage, is "just an unsatisfactory piece of equipment for that work * * * is distinctly impractical * * * they have not been successful."

The testimony for the plaintiff on the question of masks shows that, entering the defendant's employ in June 1929 and leaving it in February 1931 he was not given a mask for 3 months after his employment. He was then given masks which were in common use throughout the plant and wore them the remainder of his stay, but contends they were defective because dust particles seeped through the sides and through the sponge and because the mask can only operate properly with a moist sponge and the sponge could not be kept wet by workmen at the top of the screen tower as the nearest available water was kept at the bottom of the tower. Other witnesses for the plaintiff testified to the same effect, although none contradicted the testimony for the defendant as to its care and caution in selecting and providing masks. The drift of the plaintiff's testimony was that the defendant should have furnished a better mask, perhaps the air-line mask, although the testimony for both plaintiff and defendant was that such a mask, being still in the experimental stage, had not gone into general use in the industry.

Notwithstanding there is testimony for the defendant that masks were supplied all men at the opening of the Toms River plant and continuously thereafter, we shall accept as true the plaintiff's statement that he was not supplied with one until 3 months after starting work. But we shall regard this statement, in view of the plaintiff's failure even to intimate that disease developed during that period, as not bearing on the question because, according to the evidence, the disease of silicosis occurs only after exposure to silica for a long time, and, that assuming it later developed, it could not have been set up in the first 3 months of the 20 months of the plaintiff's employment without being discovered by him before the sixteenth month.

In August 1930, 14 months after going to work, the plaintiff complained that his mask did not fit and was furnished another. He testified that in October 1930, 16 months after going to work, he felt pains in his chest and in November felt pretty bad. Several weeks before the end of his employment he requested that he be furnished with an air-line mask in place of the sponge mask which he had been using. The superintendent promised to get him one. Such a mask was obtained and given to the plaintiff but, because its valve clogged repeatedly, requiring the man to take off the mask and make adjustments in the dust, it was not satisfactory and could not be adapted to the defendant's plant.

The evidence for the plaintiff as to the defendant's alleged negligence in supplying the kind of masks it did and in not supplying better ones shows the same infirmities as the plaintiff's evidence of negligence in the ventilating system previously discussed. It is controlled by the same rules of law, is subject to substantially the same observations we there made and is, we hold, equally unsubstantial. It follows it was error for the trial court to submit this evidence and permit the jury to find from it that the defendant was negligent when it does not show how better, or how else, it could perform its duty of exercising reasonable care in the circumstances.

The fourth and final ground of negligence which the plaintiff charged to the defendant was (d) its failure "to give the plaintiff proper warning, information, and knowledge of the dangerous character of its work with the sand-silica dust."

There is, of course, no question of a master's duty in this regard. He must instruct and warn his servant as to dangers of which he knows or ought to know, and of which he knows or ought to know the servant is, from the nature of things, ignorant. (Ramsay v. Raritan Copper Works, 78 N.J.L. 474; Rhobobsky v. N.J. Worsted Spinning Co., 76 N.J.L. 542.)

It is not clear that the defendant knew precisely what the effect of long exposure to silica dust would be, nor is it at all certain that it is chargeable with pathological knowledge of the subject in view of the uncertainty with respect to the matter prevailing in the medical profession.

One doctor testified: "There is no knowledge anywhere in the country today of how much exposure is necessary to produce silicosis. Nor is there any accepted standard by which one can tell whether a given set of conditions will or will not produce silicosis."

Another doctor testified: "There is no expert on silicosis because it is a state of disease that nobody, even those who claim to have experience in the matter, is able at the present time to determine what silicosis is, except they know it is fibrosis of the lung. Beyond fibrosis of the lung they do not know what it is."

At the trial the medical experts were divided into two groups on the question whether the plaintiff has silicosis at all.

Yet, unquestionably, the defendant master should have known that there is some danger from constant exposure to dust from ground quartz. Evidently, it did know it, and it realized its duty to guard against that danger by providing ventilators and respirators and then by warning its servants. The defendant, speaking through its president, said:

"We always told every man who worked in the mill the danger of the dust. We have always given without expense to them the most effective mask we could find for that purpose. We have told them they must wear these masks at all times there in the mill on duty. We have shown them how to wear masks, how to adjust them, how to clean the sponges. We have provided facilities for cleaning the sponges and we have seen that they do wear the masks * * *. The supply of these masks was kept in an accessible place, and the employee was permitted to help himself to them."

The foreman of the plant testified that the men uniformly were told that dust was injurious to health and they should wear masks and try to prevent it.

Opposed to this the plaintiff testified that he was not so warned. Yet the fact is, he was supplied with masks and wore them, and the fact remains, not disputed, that the defendant supplied masks generally and instructed the men in their use. The defendant's act of supplying the plaintiff with masks and the plaintiff's observation that it supplied his fellow workers with them are warnings in themselves for, obviously, a master would not have required his servants to undergo the inconvenience of wearing masks and, indeed, the servants would have refused to wear them, unless there were some reason for their use. We think the real trouble on this issue of warning is that the plaintiff complains that the defendant did not warn him of the pathological effect of inhaling silica dust. This may be true but it is not certain that the defendant knew or should have known it in time reasonably to warn the plaintiff. We find no evidence on the part of the plaintiff charging the defendant with knowledge of the disease. Nor is there evidence that

the disease normally follows contact with silica dust, or what conditions will produce the disease, or how long it takes to develop, or, when developed, what precisely is its character. We find it difficult to believe that an employee of normal intelligence working in dust has to be told that inhaling dust of any kind in large quantities is injurious for, obviously, when he is handed a mask and put to work with other men wearing masks in a place equipped with artificial ventilators, that is a plain enough warning that dust is deleterious. We cannot find, on the plaintiff's showing, substantial evidence that the defendant failed in its duty to give the plaintiff adequate warning of the dangerous character of his occupation.

We are constrained to hold that the learned trial court erred in submitting the case to the jury and in refusing to direct a verdict for the defendant on the ground that the plaintiff had failed to prove by substantial evidence any one of the four allegations of negligence on which he rested his case.

As the decision on this question is dispositive of the case, we shall, without reviewing the other questions, decree that the judgment below be reversed, a venire de novo issue, and that any further proceedings shall be conformable with this opinion.

A true copy: Teste: Clerk of the United States Circuit Court of Appeals for the Third Circuit.

As an example of preventive regulations applicable in dusty industries, the following provisions on dust are quoted from the Standards for Safety and Health for the Crushed Stone, Sand and Gravel, and Slag Industries, approved by the National Industrial Recovery Board on December 7, 1934 (424):

Appendix B, Article I--Definition of Dust Hazard

A dust hazard shall be deemed to exist in any plant where the air breathed by an employee at any point in the normal breathing zone contains particles of dust composed of free silica when the dust count thereof shall exceed 5 million dust particles of a size less than 10 microns per cubic foot of air, as determined by the U.S. Public Health Service Technique, described in Reprint No. 1528 from the Public Health Reports, vol. 47, no. 12, March 18, 1932, entitled "The Impinger Dust-Sampling Apparatus." Variations in the percentage of free silica content will make proportional changes in this standard.

Article II - Exhaust Ventilation

Exhaust ventilation shall be provided, wherever practicable, in connection with all equipment and processes which create a dust hazard in the normal breathing zone of employees. Such exhaust ventilation shall comply with the requirements of "Rules Relating to the Removal

of Dust, Gases, and Fumes" adopted by the Department of Labor of the State of New York, effective January 1, 1931, as provided by Bulletin No. 12 of the Industrial Code of the State of New York.

Article III - Protective Equipment

Whenever and wherever a dust hazard shall exist in an industrial operation, the employer shall supply the employees with respirators sufficiently effective to render the air breathed by said employees nonhazardous, as hereinabove defined. Face respirators shall be of the type certified and approved by the U.S. Bureau of Mines, Schedule No. 21.

The use of protective equipment, as provided by this article, does not relieve the employer of the obligation imposed by Article II to install exhaust ventilation.

Article IV - Packaging of Ground Sand

For packaging ground sand the use of cloth bags is prohibited.

Article V - Physical Examination of Employees

1. Subsequent to the effective date of these Standards of Safety no person shall be employed where there is a dust hazard, as defined in these Standards of Safety, unless his physical fitness to engage in the duties for which he is to be employed has been determined by a physical examination, which examination shall include an X-ray of the chest.

2. Employers shall cause all employees exposed to a dust hazard, except those employed prior to the effective date of these Standards of Safety, to be subjected to an annual physical examination, which examination shall include an X-ray of their chest to determine their physical fitness to continue in the duties for which they are employed.

3. Employers shall not permit employees suffering from active tuberculosis to engage in duties where a dust hazard exists.

Article VI - Notice and Warning

Employers shall post and display in a conspicuous place in each plant a notice, advising employees:

1. That the inhalation of silica dust is injurious to health;

2. That the use of protective equipment is necessary when exposed to a dust hazard; and

3. That the failure of employees to use such protective equipment shall render such employees subject to discharge.

Article VII - Good Housekeeping

1. Respirators.- Employers shall cause respirators to be inspected daily and maintained in the highest state of efficiency and shall provide a dusttight receptacle in which such respirators, marked with the user's name, shall be kept when not in use.

2. Plant cleaning.- Working areas whereon dust is deposited in harmful quantities shall be cleaned at regular intervals.

3. Maintenance of equipment.- Exhaust and collection systems and all protective equipment shall be inspected at regular intervals and shall be maintained in effective working condition.

4. Designation of inspector.- Each employer shall designate a competent, responsible person, specifically charged with the duty of inspecting and repairing exhaust systems, respirators, machinery, and equipment. Such person shall instruct employees in the use of protective equipment, supervise the use thereof, and be responsible for the enforcement of the provisions for good housekeeping.

Advisory Recommendations for the Protection of Employees from the Hazards of Dust for the Crushed-Stone, Sand and Gravel, and Slag Industries

Article I - Dust Counts

The use of dust counts is recommended for the purpose of obtaining information as to the existence of dust hazards and, if taken periodically, will determine the effectiveness of dust-eliminating equipment. With respect to the method of taking dust counts, the following suggestions are made:

1. Wherever practicable, dust counts should be taken by the impinger method, as described in Reprint No. 1528 from the Public Health Reports, vol. 47, no. 12, March 18, 1932, published by the United States Public Health Service.

2. Standard equipment and competent personnel should be used, and the results should be interpreted in the light of the variable factors involved.

3. In those cases where it is impracticable to use the Impinger method of sampling dust the count should be taken by other approved methods and calibrated to the impinger method.

Article II - Exhaust Ventilation

Prior to the installation of exhaust ventilation, it is recommended that dust existing in the plant be eliminated, as far as is practicable, by one or a combination of the following methods:

1. Isolation or segregation of the dust-producing operations in separate departments or buildings.

2. Completely enclosing or housing the dust-producing operations within a department.

3. The substitution of nondusty processes for dusty processes.

4. The installation and perfection of natural-draft ventilation.

All exhaust ventilation systems should be so located with respect to the plant:

1. That the discharge therefrom will prevent dust in harmful quantities from entering the normal breathing zone of workers in and about the plant; and

2. That injury to property is averted and no nuisance is created.

Article III - Protective Equipment

In order to make the use of protective equipment most effective, employers should instruct employees to follow the recommendations and suggestions of the manufacturers of such protective equipment as to the use thereof.

Article IV - Packaging of Unground Sand

For packaging unground sand, the use of paper bags is recommended. Where cloth bags are used, such bags should be lined or walled with paper. In the event that unground sand is sold in cloth bags, the return of such cloth bags to the producer should be prohibited, so that employees will not be subject to the dust hazard of handling and cleaning such bags.

Article V - Physical Examination of Employees

The physical examination of employees should include:

1. Examination of employees, including fluoroscopic examination, by competent physicians, expert in the diagnosis of pulmonary diseases.

2. The obtention of a complete industrial and medical history of employees, together with the tubercular history of the employee's family.

3. It is desirable that X-ray examination of the chest should be made by stereoscopic films; in the event that flat films of the chest are taken and such films indicate any lung pathology, they should be supplemented by stereoscopic films.

Article VI - Good Housekeeping

Orderliness and cleanliness are important factors in dust prevention. When properly supervised and practiced, good housekeeping will prove to be one of the most effective methods of eliminating the dust hazard. Due to the different problems that arise in different plants, no set rules can be established as to the methods to be used for cleaning. However, the following suggestions are made for use wherever possible:

1. Cleaning by air pressure should not be permitted except where absolutely necessary.

2. Floors and walkways should be cleaned daily.

3. Walls, overhead structures, and equipment should be cleaned by means of a vacuum system.

4. Sweeping should be done wet and at the end of the shift.

5. During the cleaning operation, protective equipment should be worn by those engaged in the cleaning process.

The following court decision (422) indicates conditions presented to employers and insurers in the courts in connection with silicosis damage suits:

There have been a number of interesting decisions on silicosis claims within the last year or two, such as Defilippo's case, 188 N. E. 245, which was decided in the Supreme Judicial Court of Massachusetts on December 6, 1933.

There were two insurers; the Standard Accident Insurance Co. ceased to be the insurer on January 10, 1932, and The Service Mutual Liability Insurance Co. became the insurer on January 15, 1932. The board found that the employee became totally incapacitated for work on February 11, 1932, and that "the accumulation of dust in the employee's lungs absorbed during the period from January 15, 1932, to February 11, 1932, was sufficient to cause and did cause the final break-down on the latter date." The court held "that an insurer under the workmen's compensation act must take an employee as he may happen to be during the term of the policy. It is immaterial that the employee is unusually susceptible to personal injury, or to serious consequences in the

event of personal injury, or that personal injury is impending because of the cumulative effect of years of exposure to the hazards of the trade. Here the employee was found to be incapacitated for work on February 11, 1932. The amount of dust inhaled during the 4 weeks immediately preceding was, in the opinion of experts, sufficient to be 'detrimental', and a 'perfectly possible cause of his incapacity.' Since the condition from which he was suffering was cumulative, the dust inhaled during the last period of labor before incapacity became manifest was most likely to be decisive. The finding of the board that it was the last straw which broke down the employee's capacity for work, cannot be pronounced as being unsupported by evidence."

In this case it is to be noted that the insurance carrier during the last 4 weeks of the man's employment was held responsible for the disability which became evident during the last 4 weeks, even though the man had worked for a long period prior to that.

By the same logic used by the court in rendering the decision in this case, the same rule would undoubtedly be laid down if the employee had two different employers.

If such were the case, and the second employment started on January 10, 1932, the second employer would be liable for the employee's disability even though the employment only existed for about 4 weeks, because as the court said in its decision, "it was the last straw which broke down the employee's capacity for work."

The decisions of the Supreme Court of Massachusetts are looked up to by courts in most States, and for that reason this decision is very important in the silicosis situation, because it will undoubtedly be followed.

In Massachusetts silicosis is under the workmen's compensation act, but so far as the common law is concerned, in common-law cases this decision will be followed with reference to the determination of the happening of the accident -- which the decision determines to be during the last period of work, or the period in which the employee became incapacitated.

It is quite evident, therefore, that it will be highly important in the future for employers, whether a silicosis action is under the workmen's compensation act or not, to have proper and sufficient clinical and X-ray examinations of prospective employees before they are put to work.

Otherwise, employers will hire employees who have been engaged in the same line of employment, many of whom will be potential silicosis claimants in view of their preexisting condition. The medical authorities will agree that the sickness resulting from silicosis does not always make itself evident at the time; its contraction might become manifest at any time.

With regard to the statement above that the last employer may be liable for the employee's disability it is interesting to note that the Pennsylvania Commission on Compensation for Occupational Diseases (425) suggested that "the employer in whose employ the claimant was at the time of the disability shall be the one who shall pay the compensation provided that his employment was the one wherein the claimant's disease was contracted or aggravated with the possible addition of a provision by which such employer can secure contributions from prior employers." It was also suggested that the employer protect himself by obtaining from the employee at the time of employment a statement of previous attacks of the disease which is naturally incident to the employer's business.

In discussing silicosis claims from the viewpoint of insurance coverage Kellogg (410) states:

> The principal difficulty is due primarily to the uncertainty existing as to the causes and progress of the disease and the difficulty of making proper diagnosis. The extent to which these difficulties will be solved will depend upon the method of adjudicating silicosis claims. Any method (whether common law or workmen's compensation) which depends primarily on the introduction of medical testimonies of not very thoroughly trained experts will lead only to "confusion worse confounded."
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> The difficulty in respect to medical testimony is twofold. In the first place, with the present state of medical knowledge, there is ample opportunity for honest differences of medical opinion. But this same condition also gives opportunity for dishonest differences of medical opinion. Medical testimony (particularly when compensated on the contingent-fee basis) may be so warped as to be totally worthless. Where the legal procedure does not provide for medical examination before trial, the opportunity for dishonesty in medical testimony at the trial is greatly increased. Furthermore, mere objective physical examination of a claimant will not show the full picture. The past history of the claimant as to exposure to possible injurious dusts must be known. With a disease of such slow progress as silicosis, this may cover a period of several years and several different employments. Without adequate preliminary examination, both medical and as to past employment history, it is impossible to adequately prepare the defense against a claim of injury by silicosis, whether brought under the common law or in a workmen's compensation proceeding.
>
> Proper procedure for the adjudication of claims for silicosis must include the submission of every claim to a competent and impartial medical board. The claimant himself should be required to submit to physical examination, including X-ray examination. If the claim be made by the next of kin or dependents of the deceased employee, then there should be in each case an autopsy conducted by a medical man of experience in the diagnosis of silicosis. * * *.

The medical board, of course, should be a State-controlled agency. It should be independent, on the one hand, of the labor department of the State and, on the other hand, of the insurance carriers. But all three should cooperate toward a solution of the problems of prevention and control. For prevention and control are of far more value to everyone concerned, be he employee, employer, or insurance carrier, than is compensation. If the hazard can be materially reduced it will become an insurable risk.

Kellogg (410) states that enforcement should be in the hands of the controlling authority; he considers a method by differentials in insurance rates the most efficient. This would reward the employer who adopts advanced methods of control and prevention and would penalize the one who fails to do so — a much more effective method of enforcement than fining employers by court procedure.

Although such disproportion may not be warranted McCord (426) states that concern over health hazards in the foundry industry may be divided in the ratio of 99 percent of dusty-lung diseases and 1 percent for all others combined. In an article entitled, "Health Hazards in the Foundry", published in the National Safety News, January 1934, he discusses the following points which, although not major problems in connection with dust diseases, he considers important to the employment manager, safety engineer, and plant physician: (1) How shall the foundry operator protect himself against cases of dusty-lung diseases originating in other plants? (2) What shall be done with the worker known to possess dusted lungs? (3) Are some races more susceptible to dusty-lung diseases than others? (4) How necessary are dust counts in detecting hazardous work points in a plant? (5) What medical defense may be invoked in litigation? Under (5) he lists the following items which have been used or are in prospective use in preparation for defending silicosis compensation suits:

1. Denial of the existence of dusty-lung disease.- Recently in the examination of a sample of 202 films of men exposed and unexposed to dust, one was singled out as exceptionally free of even usual amounts of fibrosis. This film was examined as an unknown, as were all others. Later it was pointed out that the workman from whom this film was made was a litigant demanding a large sum of money on account of alleged silicosis. Similarly, about 4 out of 5 litigants alleging dusty-lung disease are in fact free of such diseases. The claims are spurious and may be proved so by appropriate examinations carried out by qualified investigators.

2. The denial of disability or prospective disability.- A large number of workmen whose lungs show some signs of dust action are not incapacitated, and no proof exists that real disability is an early prospect.

3. The denial of neglect.- Many of the true cases of dusty-lung disease have been developing over long periods of years, such as 15, 25, or 40. Since the medical profession has possessed scant knowledge of these diseases during these periods, it is unreasonable to believe that the industrialist could have possessed more.

Inevitably it follows that operators of dusty industries may not be presumed to have possessed earlier and greater information of these occupational diseases than physicians, industrial hygienists, State health departments, State factory inspectors, and other agencies devoted to health conservation. No industrialist may be charged with neglect for failure to supply protection against an insidious disease unknown or little known to the medical profession. Even at this time the average physician possesses meager information about these conditions.

4. The origin of the dusty-lung disease in previous employment.- Manifestly it is unjust that a few weeks of employment in some one foundry should be held responsible for a well-established dusty-lung disease when antedating this employment there have been years of exposure in similar work in other plants.

5. The origin of the dusty-lung disease from causes other than industrial employment.- In some localities it seems probable that sufficient dusts may arise from roads, farmwork, etc., to induce characteristic involvment of the lungs.

6. The actual quantity of dust present in an industry is below any reasonable threshold of probable production of damage.- The mere fact that an industry or department is classified as a dusty operation is not in itself proof of the possibility of development of pneumoconiosis. The nature and extent of protective devices may fully exculpate the plant as a practical hazard. Dust-count methods have certain undeniable limitations, but this form of testing along with tests of the efficacy of ventilating apparatus may be utilized on occasion wholly to eliminate any justification for contentions that air dustiness prevails.

7. Diseases other than pneumoconiosis may account for abnormal states in the lungs or other chest contents.- At least 10 other diseases may so simulate pneumoconiosis as to permit confusion and error. Among others are fungus diseases, tuberculosis, especially disseminated tuberculosis, cancer, syphilis, pleurisy with calcifications, certain types of unresolved pneumonia. In addition, claims are known to have arisen alleging pneumoconiosis when in fact the pathology centered about such unrelated conditions as aneurysm, mediastinal tumor, anaphylactic asthma, valvular heart disease, etc.

8. Silica is not a poison.- In some States claims at law must be based upon acts applicable only to poisonous substances. What constitutes a poison is a matter of definition. At the present time the best thought as to the action of silica within the lungs is unfavorable to acceptation of it as a poison. Primarily silica action is physical rather than chemical.

9. Pneumoconiosis does not constitute an accidental injury.- In some instances it has been contended that dusty-lung states are accidental injuries. Such specious arguments ordinarily are put forth in an effort to obtain compensation in political States where no provisions are made for occupational diseases. Every valid concept prompts the recognition of the pneumoconioses as occupational diseases.

According to McCord (426), of every hundred undisabled men properly examined a fair percentage is likely to present some degree of clear-cut pneumoconiosis. Many are not disabled; some are outstandingly hale and hearty. Shall they be told of their state? Many are likely to develop mental quirks and neuroses. Some will take an unfair advantage of the employer through claims. He epitomizes what he calls a small consensus of mature and fair-minded opinions as to appropriate action as follows:

> Seek to eliminate further exposure to the dust hazard. Do not apprize any undisabled workman of his condition. Make repeated X-ray examinations at about 6 months intervals. If advancement in the condition appears, then take action suited to the individual case and the respective State in which the cases may arise. Otherwise keep these men at some work.
>
> It is not maintained that this is a perfect line of procedure. Many ethical and moral considerations arise. A year or two hence an entirely different lot of concepts may govern the situation.

In a number of States commissions have been appointed in the last year or two to study compensation for industrial diseases, especially dust diseases.

The Special Industrial Disease Commission of Massachusetts (427) after a study of working conditions in 314 granite establishments and 225 foundries of that State made the following recommendations:

> Definitions.- Wherever used in these recommendation, the words here listed are defined as follows: (1) The "granite industry" shall include all establishments where granite or granitic rock is quarried, surfaced, polished or otherwise machined or finished; (2) the "foundry industry" shall include all establishments where ferrous or nonferrous metals are cast in sand molds; (3) "siliceous" dust shall mean dust containing either silica or silicates in amounts which may be harmful to health; (4) "harmful" shall mean capable of causing personal injury, as determined by the department of labor and industries; (6) "silicosis" shall mean that form of pneumonoconiosis caused by the inhalation of siliceous dust other than that of asbestos; (6) "asbestosis" shall mean that form of pneumonoconiosis caused by the inhalation of asbestos dust.

1. Preventive regulations.- That the Department of Labor and Industries be directed to prepare and issue, under authority of chapter 149 of the General Laws, rules and regulations specifically applicable to the granite and foundry industries for the protection of persons engaged in those industries from diseases caused by the inhalation of dust, such rules and regulations to emphasize (a) removal of the dust at the source wherever possible, (b) the obligation of employees to utilize, as required by the rules and regulations, such means of protection conforming thereto as are furnished to them, and (c) the requirements embodied in the following recommendations numbered 5 and 6.

2. Certificate of compliance with regulations.- That legislation be enacted to provide (a) that no person shall engage in any business to which the rules and regulations proposed in the preceding recommendation are applicable without a certificate of compliance with the rules and regulations, such certificate to be issued by the Department of Labor and Industries and to be revocable for cause, and (b) that the proposed statute become effective 9 months after the effective date of the rules and regulations.

3. Employers must provide insurance.- That the workmen's compensation act be amended to provide (a) that insurance under the act be compulsory, with respect to all employees whose employment involves the production of siliceous dust or exposure thereto, on all employers in the granite and foundry industries, these industries being particularly hazardous to the health of those engaged therein, and (b) that the above provision embodied in this recommendation may be extended to such other industries as the commissioner of labor and industries and the commissioner of insurance, acting jointly, may determine to involve a hazard sufficient to warrant such extension.

4. Insurers must carry certificated risks.- That legislation be enacted to provide that, as a condition precedent to the granting of a license to an insurance company to engage in workmen's compensation insurance business in this Commonwealth, it must agree (a) to insure any employer in the granite or foundry industry who is the holder of a certificate of compliance as provided in the recommendation next but one preceding and who, having applied for insurance to three insurance companies and having been rejected by them, is assigned to the licensee by the commissioner of insurance, and (b) to comply with rules and regulations to be made by the commissioner of insurance for the equitable distribution of occupational-disease losses in such risks above a fair proportion which shall be chargeable to the carrying company.

5. Entrance physical examinations.- That legislation be enacted to provide (a) that no person not previously so employed in the

Commonwealth shall engage in any occupation in the granite or foundry industry in which there may be harmful exposure to dust unless his physical fitness so to do has been determined, within the 12 months next preceding, by the Department of Public Health by means of an examination; (b) that any person not prohibited by statute or regulation thereunder from engaging in such occupation and who has not been so examined within the 12 months next preceding shall be given opportunity to be so examined within 30 days after filing with the department a written application including a signed statement that it is his purpose to engage in such an occupation; (c) that the examinee shall be notified in writing, within 10 days after such examination, whether or not he is found physically fit to engage in such an occupation; (d) that if an examinee found unfit files with the department within 10 days after such notification a written appeal from the finding, it shall be reviewed by the Medical Board of Review provided for in the following recommendation numbered 14, which board shall hold a hearing if requested by the examinee and shall render to the department a decision which shall be final and of which notice shall be sent to the examinee as hereinbefore provided; (e) that no member or employee of the department or of the board, nor any of their records, shall be subject to subpoena in connection with the case of any person so examined, nor shall any such records be made public except at a hearing as hereinbefore provided; (f) that there shall be issued to each examinee found physically fit to engage in such occupation a certificate of fitness which shall bear the signature of the examinee and the date of the examination and shall be duly executed under the direction of the commissioner of public health; and (g) that no further examination of the lungs shall be necessary as a condition precedent to such employment of a person to whom a certificate of fitness has been issued within the 12 next preceding.

6. Annual physical examinations.- That legislation be enacted to provide (a) that every person engaged in any occupation in the granite or foundry industry in which there may be harmful exposure to dust shall annually be examined by the Department of Public Health to determine his physical fitness to continue in any such occupation; (b) that no finding of such physical unfitness shall be made except on evidence of active pulmonary tuberculosis; (c) that every examinee found unfit so to continue shall be so notified in writing; (d) that if an examinee found unfit files with the above department within 10 days after such notification a written appeal from the finding, it shall be reviewed by the Medical Board of Review provided for in the following recommendation numbered 14, which board shall hold a hearing if requested by the examinee and shall render to the above department a decision which shall be final; (e) that, if the decision is contrary to the finding reviewed, the examinee shall be so notified in writing; (f) that, if the decision confirms the finding reviewed, or if an examinee found unfit fails to appeal as hereinabove provided, the Department of Public Health shall in writing notify the Department

of Industrial Accidents and the Department of Labor and Industries that the examinee has been found physically unfit to continue in any occupation as hereinbefore described and the last-named department shall so notify the examinee and his employer, if any; (g) that an examinee so found unfit may apply, not less than 12 months after such finding, for a reexamination in accordance with provisions (b), (c), (d), (e), and (f) of the recommendation next preceding, any certificate of fitness issued in such case to bear the word "readmitted"; (h) that any person who, having received notice of physical unfitness from the Department of Labor and Industries as hereinbefore provided, continues in any occupation for more than 30 days in contravention thereto or returns to such occupation except after readmission as hereinbefore provided, shall forfeit all rights to compensation for disability due to pulmonary disease under the workmen's compensation act; (i) that no member or employee of the Department of Public Health or of the Medical Board of Review, nor any of their records, shall be subject to subpoena in connection with the case of any person examined as hereinbefore provided, nor shall any such records be made public except at a hearing as hereinbefore provided; (j) that the division of tuberculosis of the Department of Public Health shall give special preference in the extension of its facilities to persons who, deprived of employment because of a finding of unfitness as hereinbefore provided, have been resident, in the Commonwealth on the effective date of this legislation or for 1 year prior to the date of such finding; (k) that the division of public employment offices of the Department of Labor and Industries shall give special preference in the extension of its facilities to the dependents of such persons; (l) that the division of public employment offices of the Department of Labor and Industries and the division of rehabilitation of the Department of Education shall give special preference in the extension of their facilities to such persons if subsequently restored to fitness for employment; (m) that every person who, having been deprived of employment because of a finding of unfitness as hereinbefore provided and being in need of relief or assistance, has been a citizen of the Commonwealth on the effective date of this legislation or for 1 year prior to the date of such finding shall, on having received compensation for disability due to pulmonary disease in the full statutory amount, or at once if ineligible for such compensation, be entitled to assistance as provided for by chapter 118A of the General Laws, as amended, irrespective of any provision thereof contrary hereto, for as long as such need and unfitness continue; and (n) that the official or body providing such assistance may at any time require that any such person be reexamined, as hereinbefore provided, in order to determine whether or not the unfitness continues.

7. Compensation for pulmonary disability restricted.- That the workmen's compensation act be amended to provide (a) that no person who has previously received compensation for disability due to pulmonary disease, either in total statutory amount or in a lump sum under

final adjudication, shall again be eligible for compensation for disability due to any such disease and (b) that, except in cases pending before the Industrial Accident Board on the effective date of this legislation, no person who has not been a resident of the Commonwealth for the 5 consecutive years immediately preceding the date of injury shall be eligible for compensation for disability due to silicosis or asbestosis.

8. All persons exposed subject to preventive regulation.- That chapter 149 of the General Laws be so amended as clearly to authorize the Department of Labor and Industries (a) to make such investigations, determinations, rules, regulations, and orders as are necessary to the protection of the health and safety of all persons engaged in any employment, as defined in section 1 of that chapter, and (b) to make such investigations, determinations, rules, regulations, and orders as are necessary to the protection of the health and safety of the public with respect to such employments.

9. Physicians' reports paid for, privileged.- That section 11 of chapter 149 of the General Laws be amended to provide (a) that the Department of Labor and Industries shall pay a fee of 50 cents for each report of disease made pursuant to the provisions of that section and (b) that no such report shall be subject to subpoena, nor shall its contents be made public.

10. Schedule and experience rating for occupational-disease risks.- That legislation be enacted to authorize the commissioner of insurance to approve or disapprove plans for computing premiums for an individual employer whose employees are exposed to dust or other occupational disease hazards, according to the existence and effectiveness of machines or devices designed to remove or reduce such hazards.

11. Cancellation of policies restricted.- That legislation be enacted to provide that no workmen's compensation insurance policy shall be subject to cancellation by either party on less than 30 days' notice in writing.

12. Division of Occupational Hygiene.- That legislation be enacted to provide for the establishment, in the Department of Labor and industries, of a division of occupational hygiene, with a director, such personnel having special knowledge of the causes and prevention of occupational disease and such additional staff and facilities as may be necessary to the efficient performance of its duties, which shall be (a) to investigate conditions of occupation with reference to hazards to health and to determine the degree of such hazards, (b) to investigate and evaluate means for the control of such hazards, (c) to assist in the preparation of rules and regulations for the prevention of occupational accidents and disease, and (d) in cooperation with the Department of Public Health to promote occupational health and safety education.

13. Occupational medical staff.- That legislation be enacted to provide that there be added to the personnel of the division of adult hygiene of the Department of Public Health a medical staff and such assistants and facilities as may be necessary to the efficient performance of their duties, which shall be (a) to investigate and report to the Industrial Accident Board on the medical aspects of all cases coming before the board for compensation for silicosis, asbestosis, or pulmonary tuberculosis and to so investigate and report in such cases coming before the board for other occupational diseases as the board may refer to them, their reports and findings to be admissable as evidence before the board or any member thereof, but no member or employee of the department to be subject to subpoena in connection therewith, (b) in any fatal case coming before them to order an autopsy if in their opinion it is advisable for the purpose of determining a fact material to any party at interest, (c) to make such findings of physical fitness as are provided for in the preceding recommendations numbered 5 and 6, (d) to study the effects upon health of materials and processes used in industry, in connection with which studies no member or employee of the department shall be subject to subpoena, and (e) in cooperation with the Department of Labor and Industries to promote occupational health education.

14. Medical Board of Review.- That legislation be enacted to provide for appointment by the Public Health Council of a board of three physicians, 1 to be a clinical pathologist, 1 a roentgenologist, and 1 a specialist in diseases of the chest, to be designated as the Medical Board of Review, whose members shall serve and be compensated on a per-diem basis and whose duties shall be (a) to review, on request by the Industrial Accident Board, reports and findings of the Department of Public Health provided for with respect to compensation cases in the recommendation next preceding, and (b) as provided in the preceding recommendations numbered 5 and 6 to review findings of physical fitness made by the Department of Public Health, hold hearings, and render decisions thereon.

15. Statistical data.- That legislation be enacted to direct and enable the Department of Industrial Accidents to prepare from its records, as a factual basis for preventive regulation by the Department of Labor and Industries, statistical data on occupational injuries.

The Medical Committee of the Pennsylvania Commission on Compensation for Occupational Diseases (425) paid special attention to miners' asthma and silicosis because it was believed that a large number of claims for compensation would be made for these diseases; also they represent peculiar problems because of their slow development over a period of years with different degrees of disability incident to particular stages of development. Miners' asthma is peculiar to the coal-mining industries, whereas silicosis may arise from the breathing of silica dust in industries other than coal mining or mining of any sort. They

are related basically, however, as dust diseases, and miners' asthma is frequently involved with silicosis. In connection with silicosis the committee recommended the following:

> For the purpose of compensation silicosis shall be considered a disease of the lungs, due to breathing air containing silica (SiO_2) dust, characterized anatomically by generalized fibrotic changes in both lungs, with a development of miliary nodulation, demonstrable by X-ray examination.
>
> The disease is divided arbitrarily into first, second, and third stages for convenience of description and possible compensation purposes.
>
> Silicosis, at any stage, when complicated with active pulmonary tuberculosis, shall be deemed total disability; in the absence of such infection only second and third stages shall be compensable.
>
> In order to establish a claim for compensation for silicosis, the claimant must have had the equivalent of 2 years' aggregate employment in the State of Pennsylvania, all occurring after the passage of the act, in an occupation or occupations recognized as involving exposure to silica dust.

Although the term "chronic incapacitating miners' asthma" was not considered entirely satisfactory or scientific it was used to indicate an affection well-recognized under that title in the coal fields by the laity and the medical profession and to represent the chief disability resulting from anthracite mining. The committee (425) pointed out that the term indicates a disabling consequence rather than the underlying causative condition and is therefore a symptom complex rather than a pathological entity. Inclusion of anthracosis itself as a compensable disease was not considered feasible because of its prevalence. The committee considers that miners' asthma incident to anthracite mining is of very great moment in the industry but that there is no comparative experience in any other State or country which would be of use in determining the extent of the disease as a compensable condition. The effect of soft-coal mining upon mine workers is different from that of anthracite mining.

The Medical Committee (425) concluded that there is a disabling occupational disease of the character of chronic incapacitating miners' asthma but, owing to the lack of precise information as to the exact nature and prevalence of the disease, recommended that a further study and investigation be made of occupational diseases among anthracite miners. In any case, it recommended that in order to establish a claim for compensation for chronic incapacitating miners' asthma the claimant must have had not less than 5 years' aggregate employment in the coal-mining industry of Pennsylvania, 2 years of which must have followed the passage of an act.

As a result of its inquiry the Medical Committee (425) concluded that approximately 22 percent of the whole group of miners are suffering from miners' asthma and are either partly or totally disabled thereby, the more active symptoms being incident to the miners engaged in rock drilling wherein the dust inhaled contains silica.

The Medical Committee (425) observed that the decisions of compensation tribunals and courts were replete with statements that persons familiar with the complexities of the subject -- diseases and pathological conditions -- could readily recognize as incorrect to the point of absurdity. It was therefore recommended that a medical board be created to assist in the operation of the act and that its findings as to whether certain conditions from which the claimant was suffering were due to an occupational disease caused by given employments should be final. Furthermore, this board should keep abreast of the development of understanding in relation to occupational diseases and from time to time make recommendations relative to the inclusion or exclusion of diseases from the list of those made compensable. The qualifications of such a board were also discussed by the committee.

Jones (428) emphasizes that the only solution of the silicosis problem lies in prevention, as the cost of compensating for it is too great for industry, however it is paid. He states:

> From what I can learn the disease now known as silicosis is as old as history. But whether because of a recent increase through the use of modern machinery or because of a growing public recognition of its seriousness, or because of these two factors in conjunction, and possibly others also, silicosis has now become a mortal menace to industry. Whether under a system of employers' liability for damages or under a system of compensation -- "regardless of fault" -- for occupational diseases, the cost of silicosis is becoming so heavy as to entail the rapid or gradual ruin of many industries, unless the incidence of the disease can be radically reduced. And cure of silicosis, once it has progressed beyond a very early stage, is, according to the preponderance of medical opinion, practically out of question. Consequently for silicosis, prevention is most emphatically the primary and principal problem.
>
> That problem has engineering, medical, economic, legal, educational, and political aspects -- all of which need to be realized by all concerned in the task of prevention.
>
> In its engineering aspects the principal problem in prevention of silicosis is the removal of or prevention of inhalation of dust. As a layman I cannot imagine how, practically, all dust can be removed or kept from inhalation. Therefore, primarily at least, efforts should probably be directed principally to the elimination of harmful dusts. Here you are confronted with several difficulties.

The preponderance of medical opinion is that, of the organic[4/] dusts constantly generated in industry, only dust of free silica (silicon dioxide) and perhaps asbestos dust -- and these dusts only when in minute particles -- are harmful -- that is, harmful in the sense and to the extent of causing specific disabling diseases of the lungs. But that is merely a majority opinion, from which there are dissents; and it is open to doubt. Only a few months ago a high authority on this subject in Great Britain declared:[5/] "We need a scientific 'recessional' in which to reexamine with an open mind many of the generalizations now accepted as current coin in relation to silicosis and 'miners' phthisis.'" Moreover silicosis is -- in colloquial language -- "all mixed up with" tuberculosis. Apparently tuberculosis may be caused by organic[4/] dust or, for all that I can learn to the contrary, may be indirectly activated by other dusts. Consequently how far all dust, or, if not all, then what dusts, imperatively need to be eliminated is, as yet, a problem to be determined largely by experimentation, not based a priori on present medical opinion, but on the results of experience -- on the results in the way of reducing morbidity from the use of specific means of prevention.

A problem of vital importance in the study of engineering means of prevention is the determination of what is practicable -- economically and humanly. Economically, the best means of prevention may often be impracticable. Industry cannot afford to be continually replacing its machinery to experiment with the latest gadgets. It would be a jump out of the frying pan into the fire to load an industry to death to prevent exposure to an occupational disease. And some means of prevention may be such that the workmen simply cannot be induced to use them properly and consistently. This problem will be particularly acute in the smaller undertakings. What is practicable in large and well-organized establishments is often impracticable in minor operations. Thus in the prevention of lead poisoning, the well-established paint factories have been almost completely successful, whereas among the job painters the incidence of that disease has been very little reduced. Results will probably be similar as to silicosis. In South Africa, where silicosis seems to be concentrated principally in mines, generally large establishments, measures of prevention are succeeding in reducing the incidence of the disease encouragingly. But in Cumberland County, New South Wales, where a scheme of compensation for silicosis applicable to such small-job trades as quarrying, rock drilling, sewer excavation, etc., is in force, it seems that little progress in prevention is being made, though strenuous medical means are resorted to. It may turn out to be a job for engineers to discover means for prevention of silicosis practicable for the "little fellow." At least that is a point which will require your study.

4/ Should be "inorganic"?

5/ Cummins, S. L., adviser to the British Tuberculosis Research Committee, quoted in Ind. Med., vol. 3, no. 4, 1934, p. 264.

This question of what is practicable, as distinguished from the ideal, leads up to another aspect of the matter. In my opinion, besides studying the best practicable ways and means for prevention, engineers should also give consideration to the formulation of minimum standards and to ways and means for procuring their observance. Authoritative formulation of such standards is needed for many purposes -- to impress backward industrialists, to guide and support insurers in granting or refusing coverage, and to furnish a scientific basis for regulations to be enforced by public authorities. A code of such standards needs to be elaborate, so as to fit different conditions, and to be open to continual revision, so as to keep abreast with the developments of research and experience.

Virtually every meeting called to consider ways and means of preventing injury to persons employed in industrial pursuits has devoted part of its program to discussion of occupational-disease problems but in nearly every instance from the medical viewpoint. Because of the close relationship between prevention of industrial accidents and prevention of occupational diseases, Ainsworth (413) states that standardization should play an equally important part in the solution of problems arising in the prevention of occupational diseases.

National standardization in the prevention of accidents developed through the necessity for bringing order out of the confusion resulting from the great number of conflicting requirements, rules and regulations, practices, and recommendations which have been prepared and enforced or recommended by the various regulatory bodies, insurance groups, trade associations, accident-prevention organizations, and others throughout the country. Bringing together around a common table the various groups, which as separate units had prepared their own accident-prevention recommendations, to iron out their differences and express their points of view, according to Ainsworth (413) has resulted in establishing authentic methods for the prevention of industrial accidents. Therefore, to prevent the same confusion in technical requirements for the prevention of occupational diseases which came about through lack of a proper national clearing house of information in the field of accident prevention, such a clearing house charged with the development of minimum standards in this particular field should be organized at the earliest possible date. Hatch (429) proposes a national board to review rules and methods and to prepare at stated intervals, for the assistance of State officials, standards of good practice for various dusty processes and industries. This program has been suggested to the American Standards Association by the sectional committee charged with developing a safety code for exhaust systems (413). As a part of this recommendation the committee suggested the appointment of a national advisory board, composed of experts in the prevention of occupational diseases, to correlate the technical knowledge now available. The work of this committee, according to Ainsworth (413), might be developed through extensive research and practical experience so that it could furnish sound technical information on the best ways and means of preventing health hazards, from the national point

of view, to technical committees organized under the procedure of the American Standards Association for the development of standards to eliminate industrial health hazards, which they in turn could give to regulatory bodies and industrial concerns. He states that the symposium held by the Safety Committee of the American Society of Mechanical Engineers undoubtedly has brought more clearly to mind the importance of the engineering aspects of the solution of problems relating to the prevention of occupational diseases and has supported the theory that proper machinery should be established for the development of authoritative national standards with which to assist the engineer in carrying on his part of the prevention program.

According to Cranch (430), in extending compensation coverage to occupational diseases it must be recognized that whatever method is pursued the subject is much more complex than that of accidents. Expert medical information is essential in administration and must be available from an impartial source to the board or commission responsible. The ultimate cost of such coverage is also quite a problem; as costs have steadily increased for coverage of accidents, despite the presumed clear-cut nature of an accident, only a guess can be made as to what the relative increase in costs would be for occupational disease.

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MINE SAFETY DECISION 27

BY

The Mine Safety Board

I.C. 6859
October 1935.

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

Mine Safety Decision 27 [1]

By the Mine Safety Board

Mining officials, as well as members of the Bureau of Mines staff, in their efforts to make mining safer are confronted from time to time with complicated problems concerning solution of which there is a diversity of opinion. To reduce these differences of opinion as much as possible and to obtain a generally acceptable decision on any mine-safety question, the Director of the U.S. Bureau of Mines established the Mine Safety Board on June 1, 1924 -

> * * * to consider questions arising within any divisions of the Bureau that require a definition of the Bureau's collective opinion as to safety practices, safety devices, or safety methods for underground operations or open-pit mining. The approved[2] decisions shall form the basis of teaching and policy for the Bureau.

Some of the 27 decisions reached by this board and approved by the Director to date relate strictly to coal mining; others to metal or nonmetallic mining; and some, like Decision 27, which follows, relate to any kind of mining in which shafts are used. The first 25 decisions were published July 1933 in Information Circular 6732 with explanatory text; Decision 26, Reducing the Amount of Gas in Mines and Tunnels, was issued as a separate publication.

Mine Safety Decision 27, Relating to the Construction of Shaft Linings[3]

In the interest of safety the United States Bureau of Mines recommends:

1. That the lining of all mine shafts shall be fireproof.[4]
2. That the lining, so far as feasible, be smooth and without projections or recesses so as to prevent:
   (a) Turbulence of the ventilating current;
   (b) Accumulation of dust, especially inflammable dust;
   (c) Lodgment of rock or other material.

1/ The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from U.S. Bureau of Mines Information Circular 6859."
2/ Approved by the Director of the Bureau of Mines.
3/ Approved July 13, 1935, by JOHN W. FINCH, Director.
4/ Decision 7, sec. 2, recommends that the "main intake shaft lining be of fireproof construction."

Explanatory Notes

The Bureau of Mines recommended in section 2, Decision 7, "that the main intake shaft lining be of fireproof construction and there be a minimum amount of inflammable material in or adjacent to the shaft." This is the general practice in European mines where most shaft linings are brick or concrete and are circular or elliptical in cross-section. For long-lived shafts such form and noncombustible construction are highly desirable because they are strong and permanent and offer the minimum resistance to air flow.

In the United States, however, nearly all shafts are wood-lined and rectangular in cross-section; they are rarely of fireproof construction, except in a few metal mines and coal mines or where such construction is required by State coal-mining regulations, as in Illinois[5] since the Cherry mine fire disaster.

As many disastrous fires in both metal and coal mines have occurred in or connected with wood-lined shafts it is evident that in the interest of safety and fire prevention, as well as for permanence, all main shaft linings should be constructed of incombustible material. If, however, wooden lining is used it should be made fire-resisting, as by covering with cement-sand coating or gunite preferably reinforced with wire mesh.

Most wooden shaft linings are made of frames or horizontal sets of squared timbers placed 3 to 5 feet (vertically) apart, with plank lagging behind the frames in contact with the rock or ground; but when the strata appear solid the lagging sometimes is omitted. In either case the timber sets project into the shaft 6 to 8 inches, or even 12 inches in heavy ground, in effect making wide shelves. The results are:

1. Scientific tests show that much ventilating power is lost through air turbulence where an air current traverses a rough duct compared with traversing a smooth lined passageway.

2. Dust collects on these shaft projections. The dust in some cases may be highly inflammable, such as coal dust and pyritic dust carried by air currents or otherwise in the shaft. Such dust, when in a dense cloud, has propagated many explosions from ignitions by open lights or electric "shorts" or arcs in the surface tipple building, in the mine below, or, in a few instances, within the shaft itself.

3. Projecting frames catch pieces of rock or coal - often large - falling from cages or skips or from the surface. These loose pieces may be dislodged by air currents, by the falling of other pieces, or by some shock and may drop on persons on hoisting cages or at the shaft landings.

If wooden timbering is used a relatively smooth lining may be obtained by using squared timbers of appropriate strength laid log-cabin fashion "skin to skin."

5/ See "Fire-Fighting Equipment in Coal Mines" (effective July 1, 1910) Illinois General Mining Laws (Sec. 6, a and b).

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